Modeling Carbon Dynamics for Agriculture and Forest Ecosystems Using the Process-Based Models

National Carbon and Greenhouse Gas Accounting and Verification System in Canada

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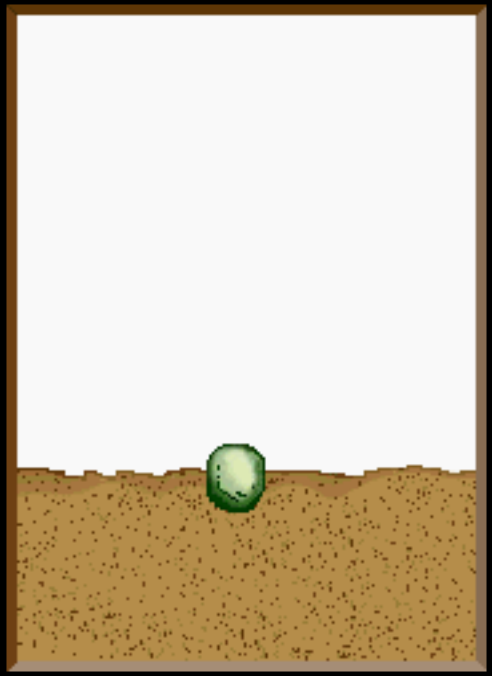
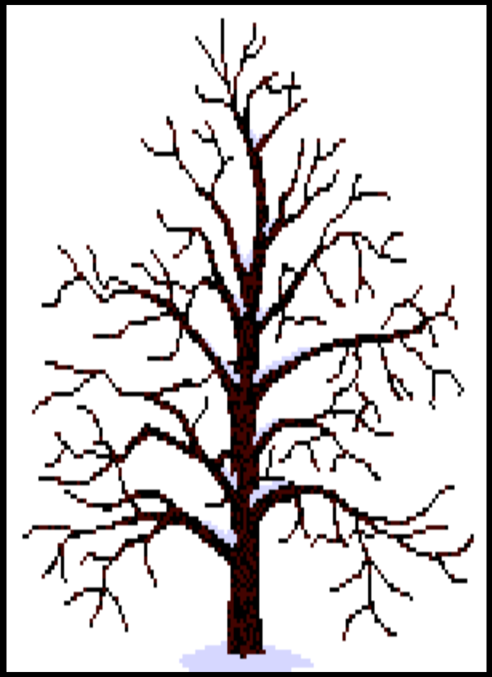
Kuo-Hsien Chang



Ph.D., University of Guelph, Canada
NSERC Postdoctoral Fellowship
Agriculture and Agri-Food Canada

August, 2011



Why I am here

- To find my "roots"
- To contribute my Ph.D. and postdoctoral projects to interdisciplinary researches in Taiwan
- To develop the greenhouse gas accounting system in Taiwan and Asia

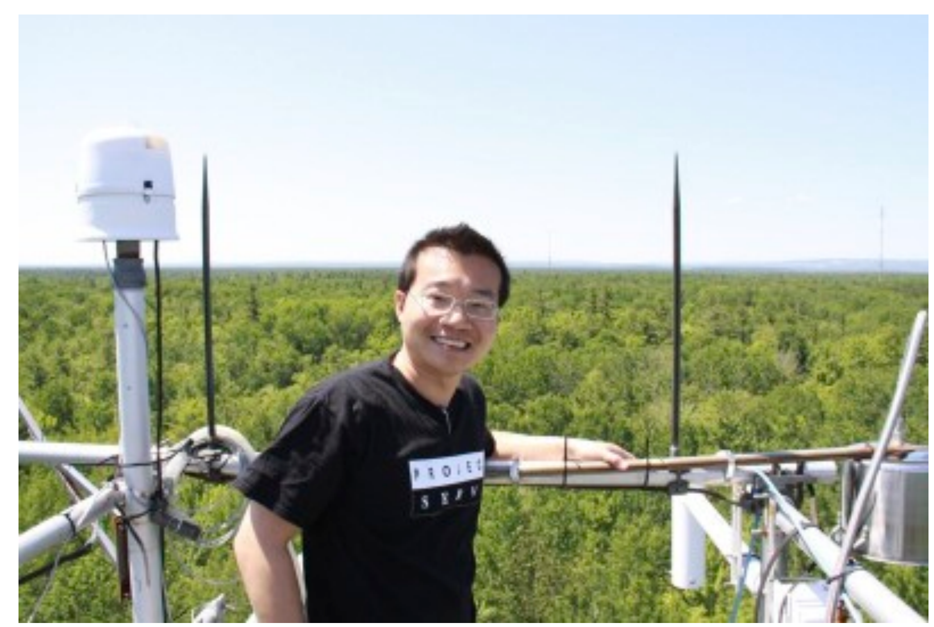
About me ...

1997 – 2001	B.Sc., Atmospheric Sciences, Chinese Culture University
2001 – 2003	M.Sc., Atmospheric Physics, National Central University
2003 – 2005	Military service, Naval Meteorological & Oceanographic Office
2005 – 2006	Assistant Researcher, Institute of Environment and Resource
2006 – 2008	Ph.D. Candidate, Ecology, Colorado State University
2008 – 2011	Ph.D., Agrometeorology, University of Guelph
2011 – 2013	Postdoctoral researcher, Agriculture Canada

Rocky Mt. Watershed Project

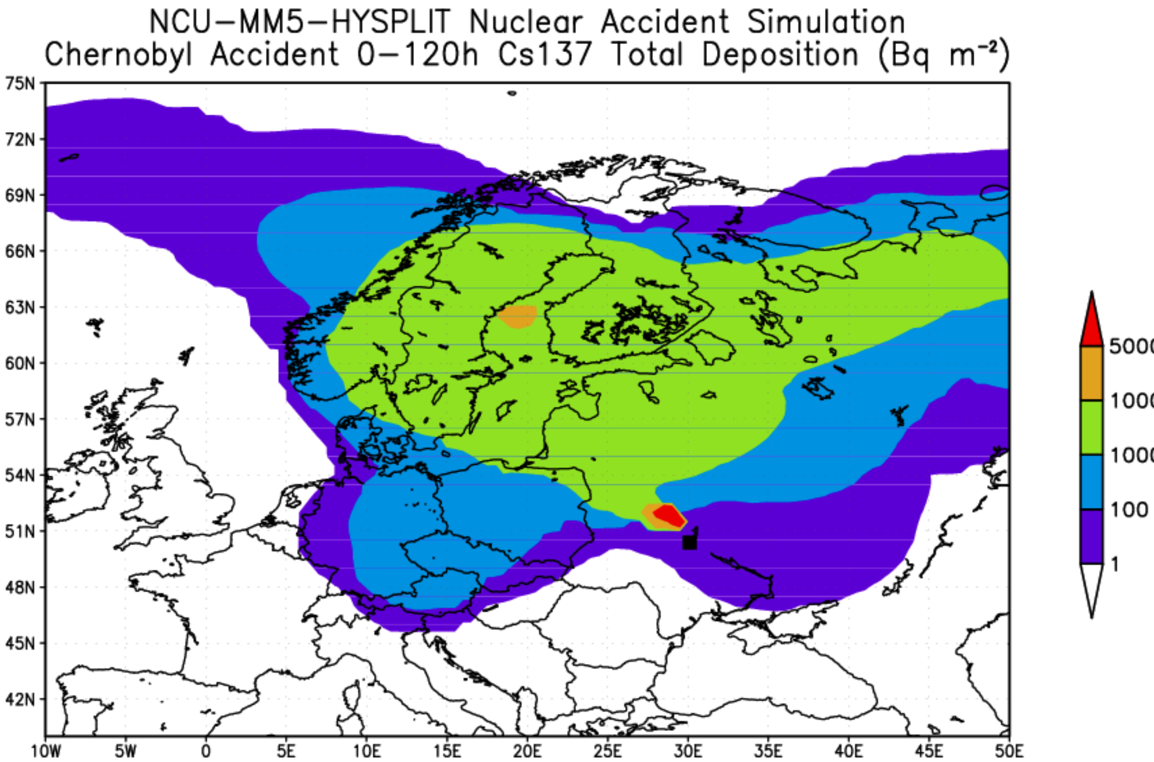
DOE SOC Project

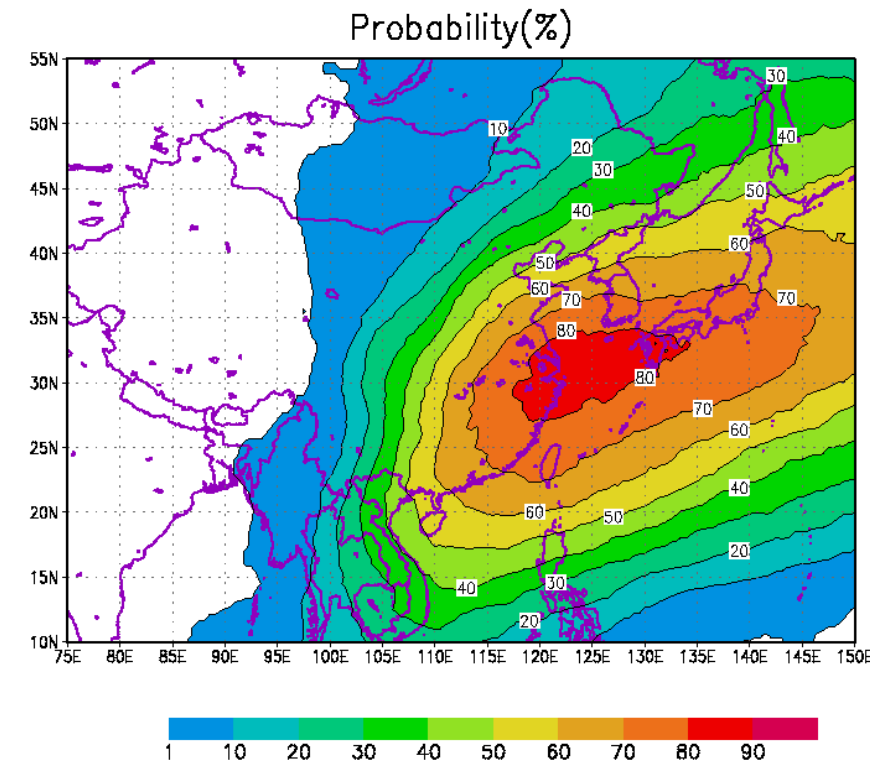
North Amer. Carbon Project



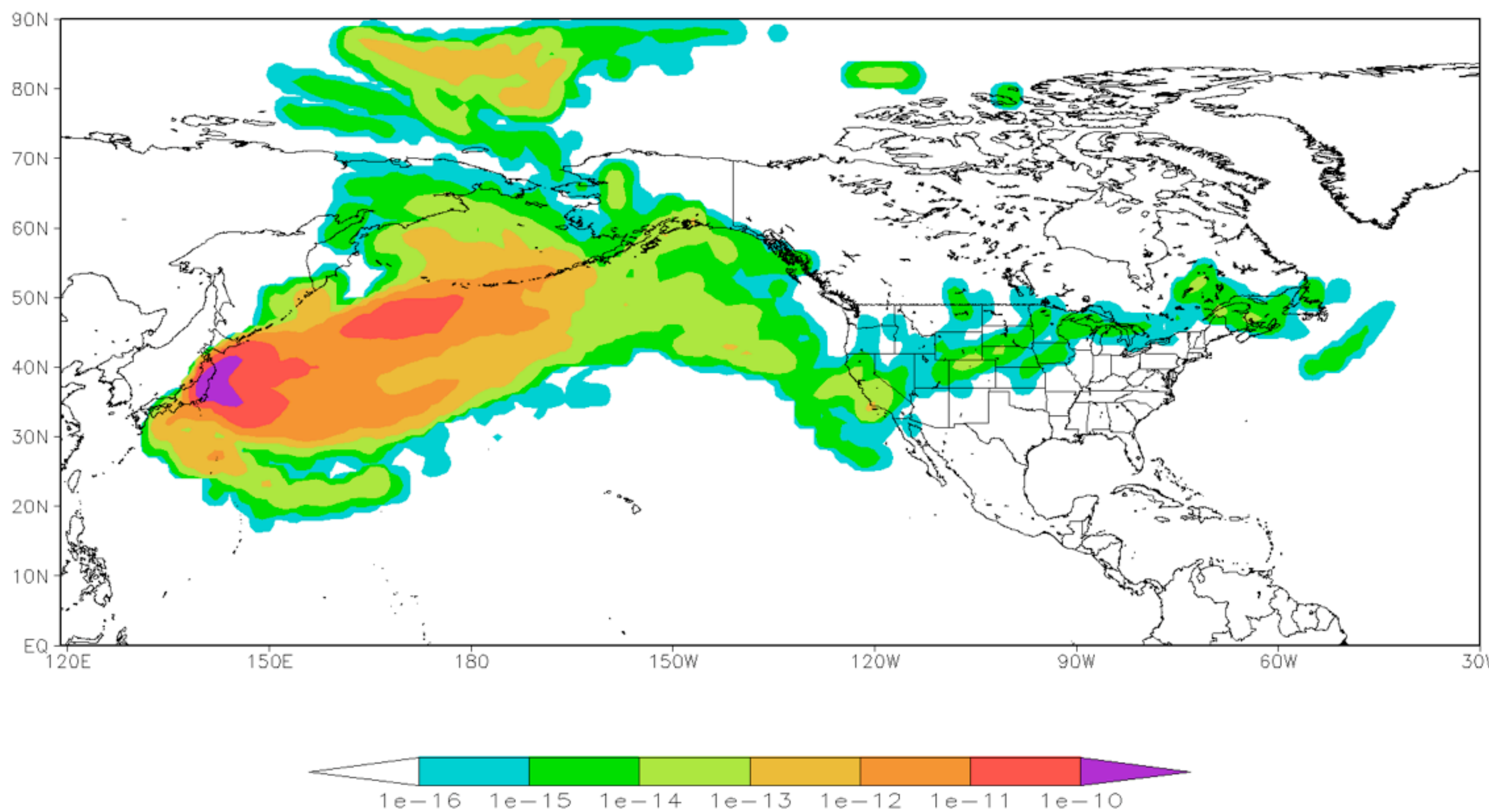
Nuclear Emergency Response System in East Asia (2003)

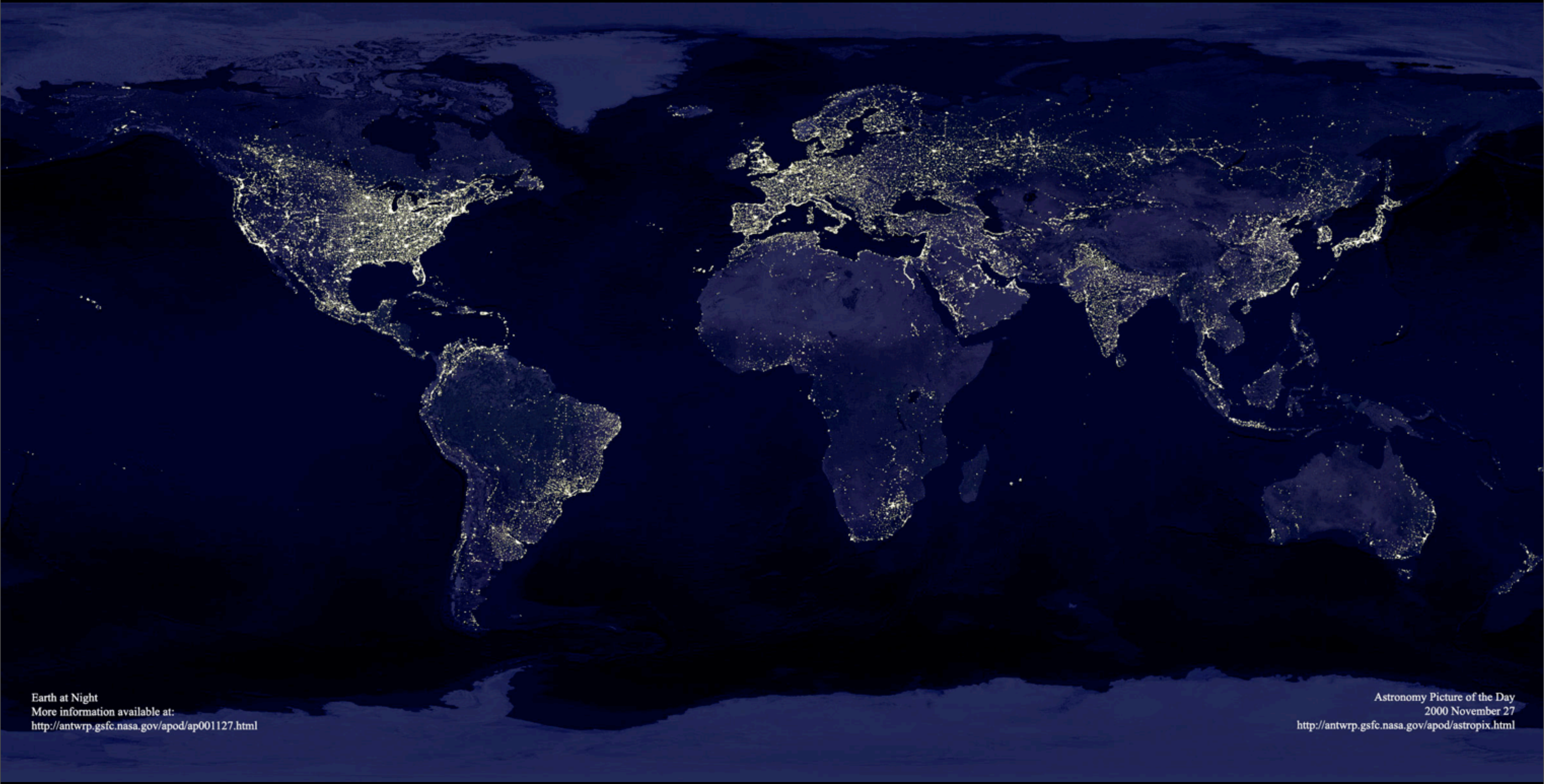
Kuo-Hsien Chang
Dept. of Atmospheric Sciences, National Central University, Taiwan





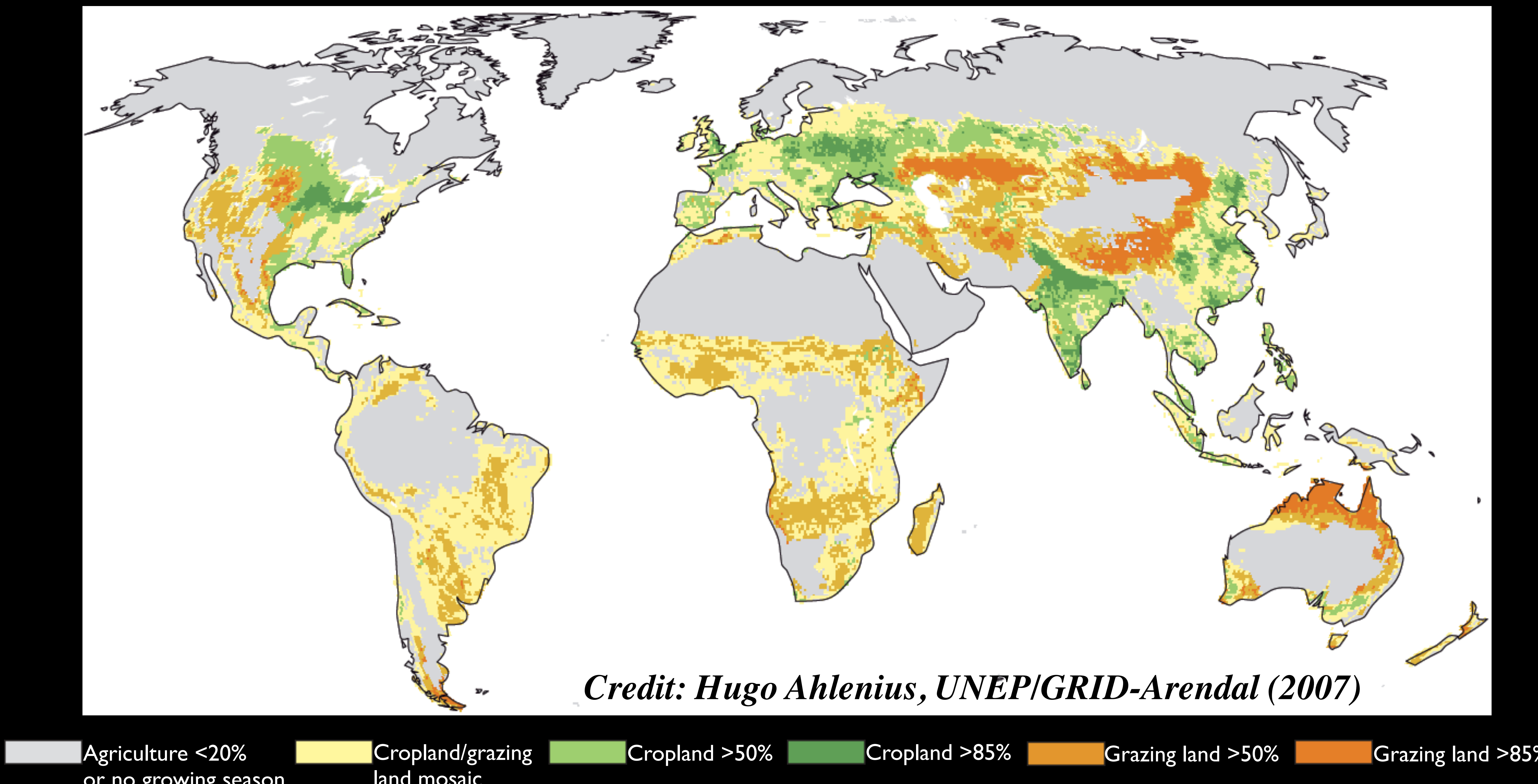
Fukushima Nuclear Accident (2011)




Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

Accounting Carbon Stock in Land Use/Land Cover

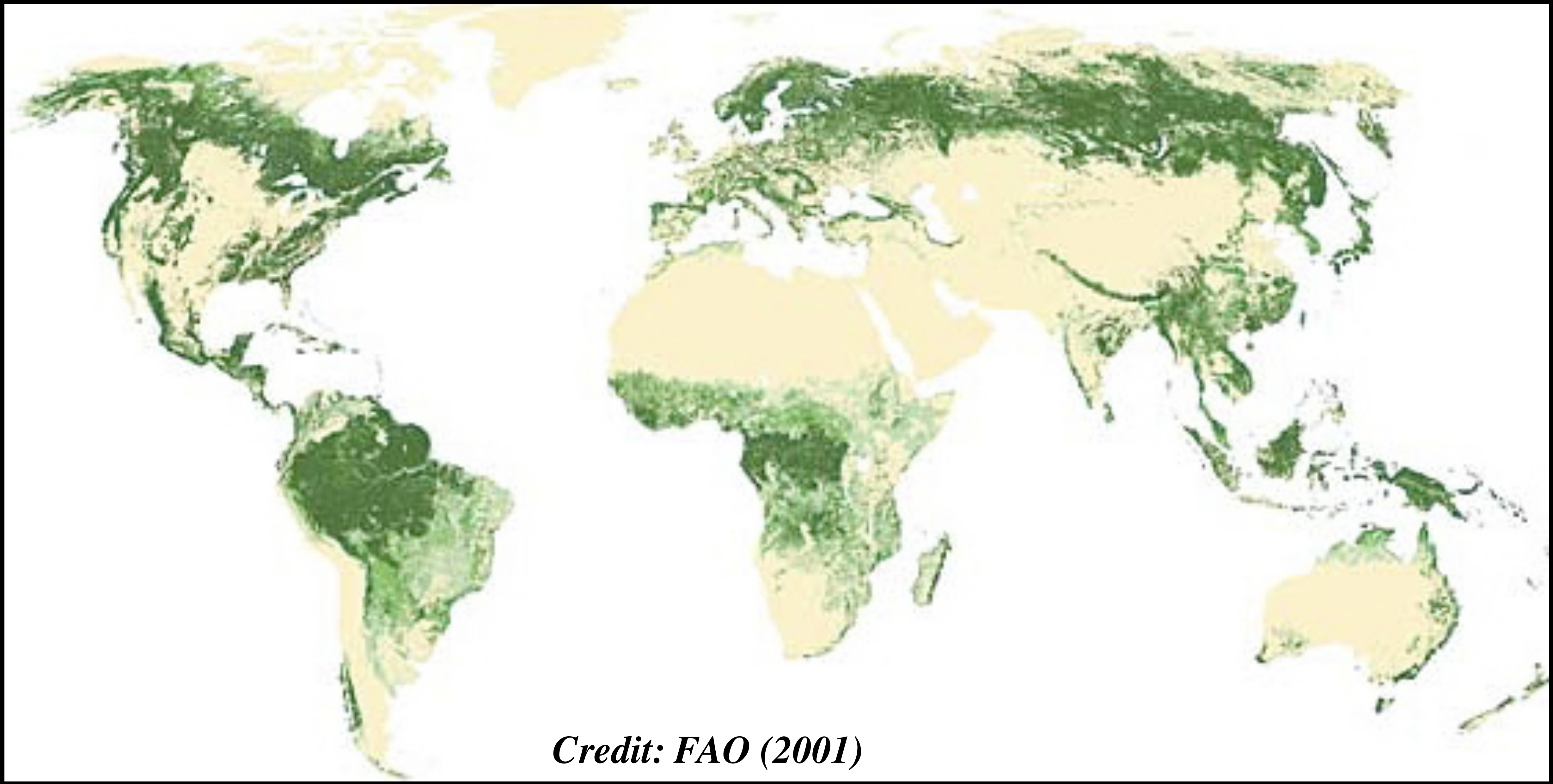
- 33% of land surface: **cropland**
- 37% of **cropland** : active agricultural practice



Accounting Carbon Stock in Land Use/Land Cover

- 33% of land surface: **cropland**
- 37% of **cropland** : active agricultural practice
- 30% of land surface : **forest**

→ **63% of global land for carbon stock**



Closed forest >40% or >5 meters high
Open & fragment forest 10~40%
Woodland / Shrubland / Bushland

Process-Based Models : DayCENT and CN-CLASS

Model	Full name	Sector	Time-step	Soil layer	Functional type	Event scheduler
DayCENT *	Daily version of CENTURY	Soil & Crop	Daily	11	User-defined	Yes
CN-CLASS **	C & N coupled Canadian Land Surface Scheme	Atmosphere	Half-hourly	3	4	No

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My Ph.D. work is to focus on :

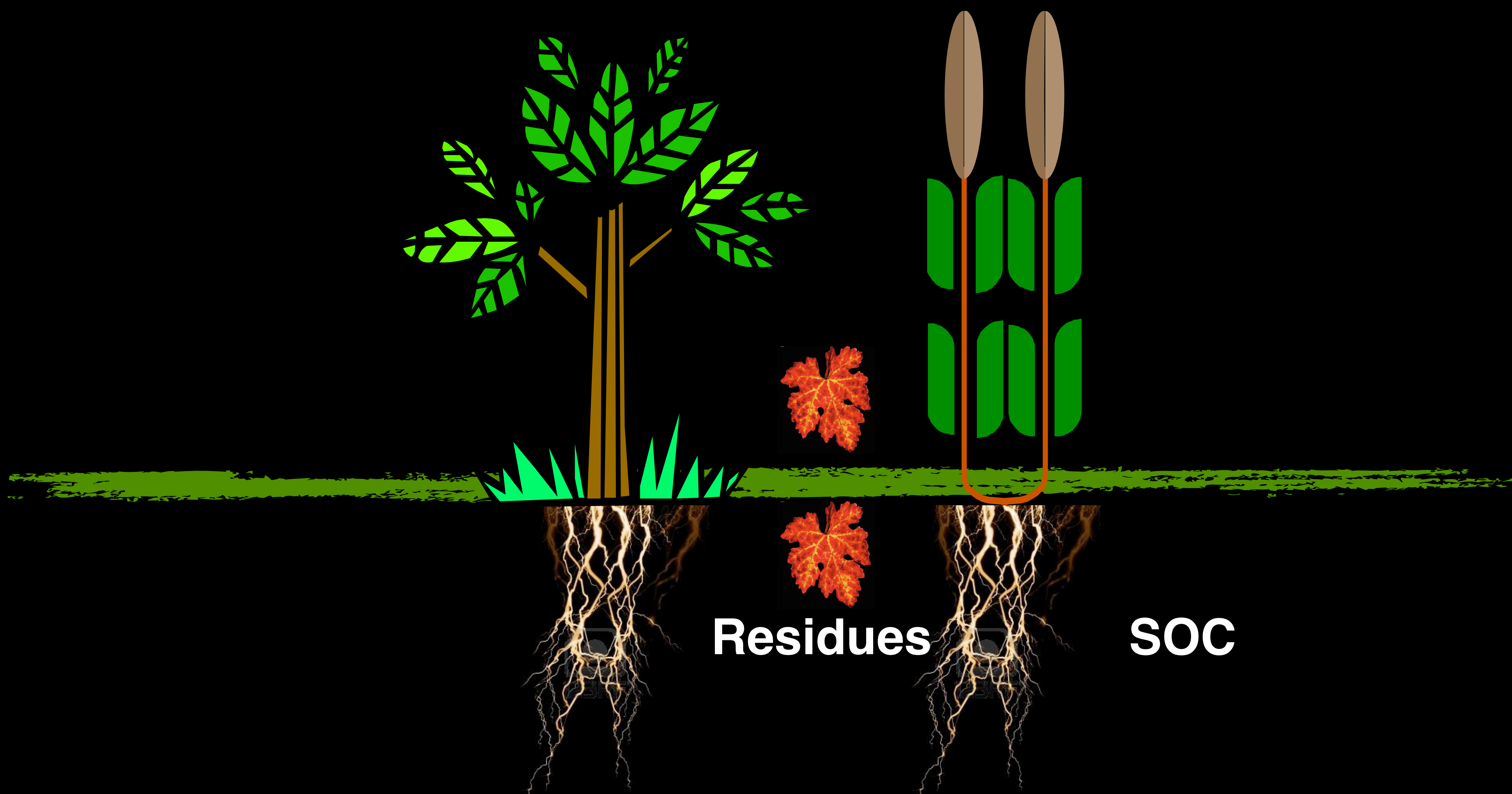
- Long-term carbon cycle simulation at daily & half-hourly time-step
- Improvement of process-based model for agriculture
- Verification of respiration algorithms in CN-CLASS for deciduous forests

Research Questions:

- How well is the process-based models able to simulate carbon dynamics and how is the uncertainty ?
- What is the effect of agricultural practices and forest litterfall on carbon dynamics ?

Carbon Flows in the Models and Field Measurement

Plant Phenology
Tillage Practices
Soil Organic Carbon



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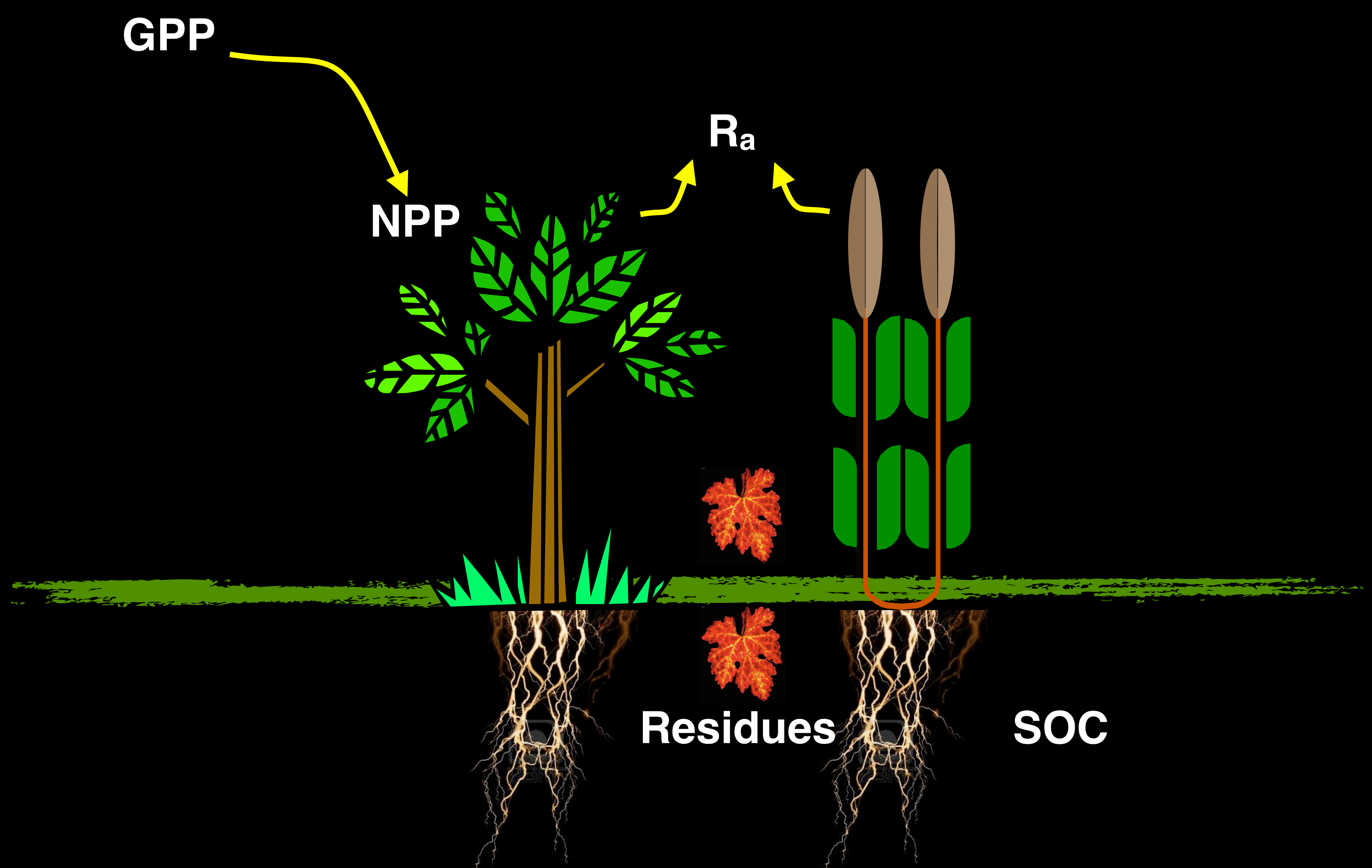
→ $NPP = GPP - R_a$



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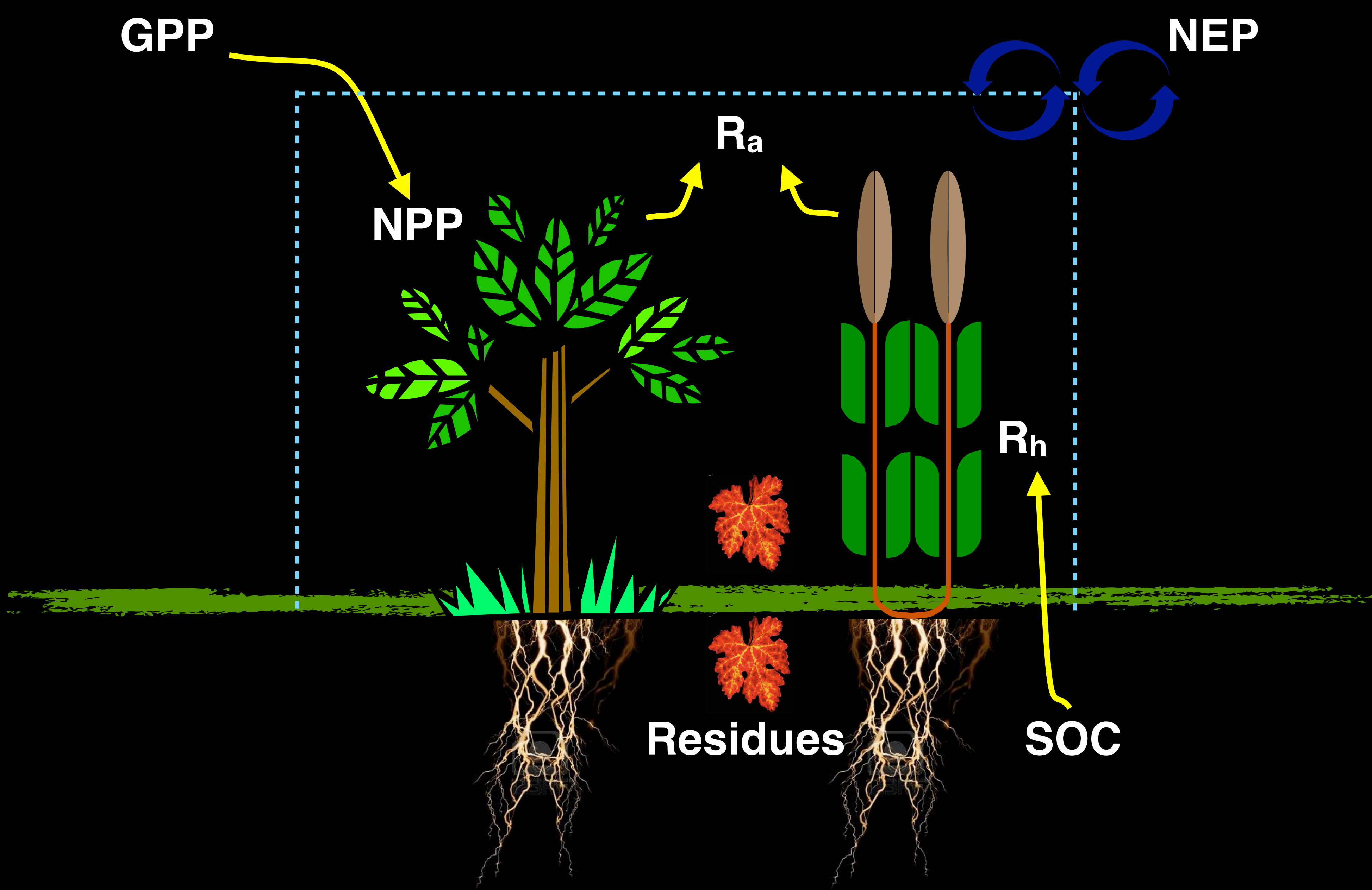
$$NEP = NPP - R_h$$



Measuring NPP & Crop Phenology

Measuring Soil Respiration

Measuring Soil Respiration

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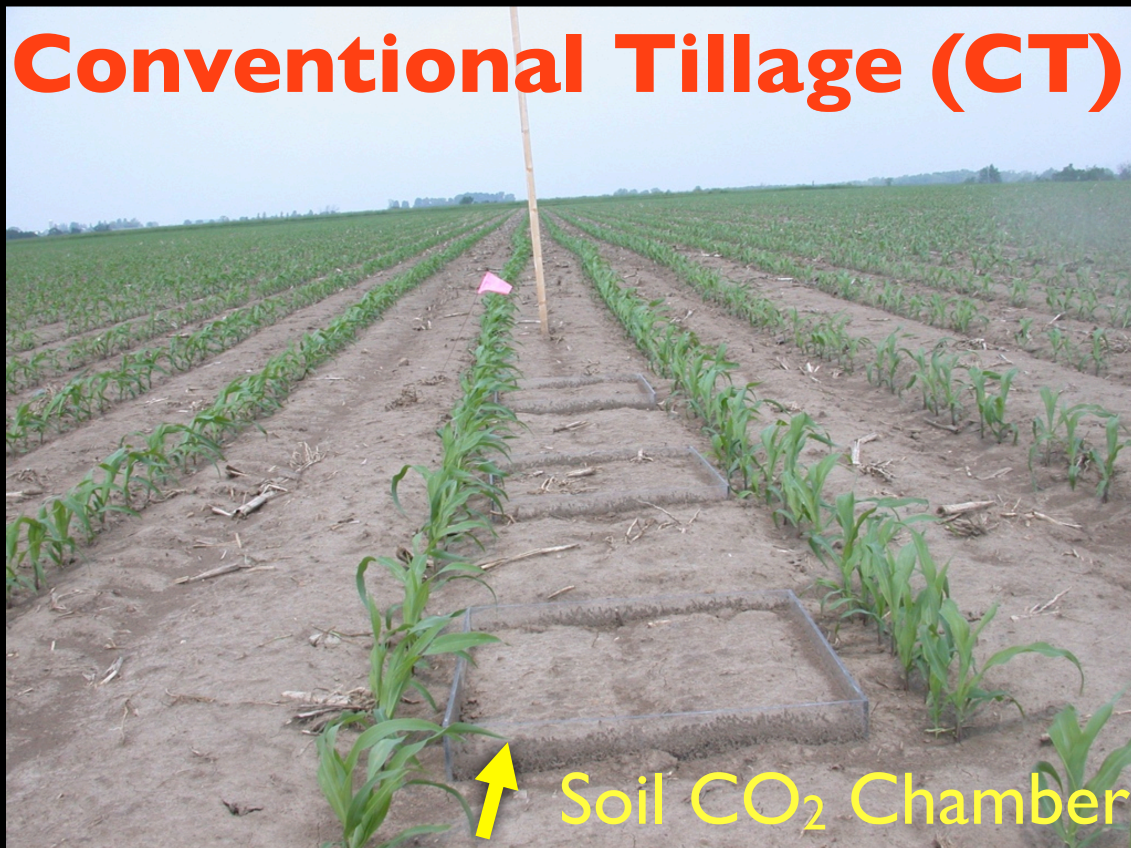
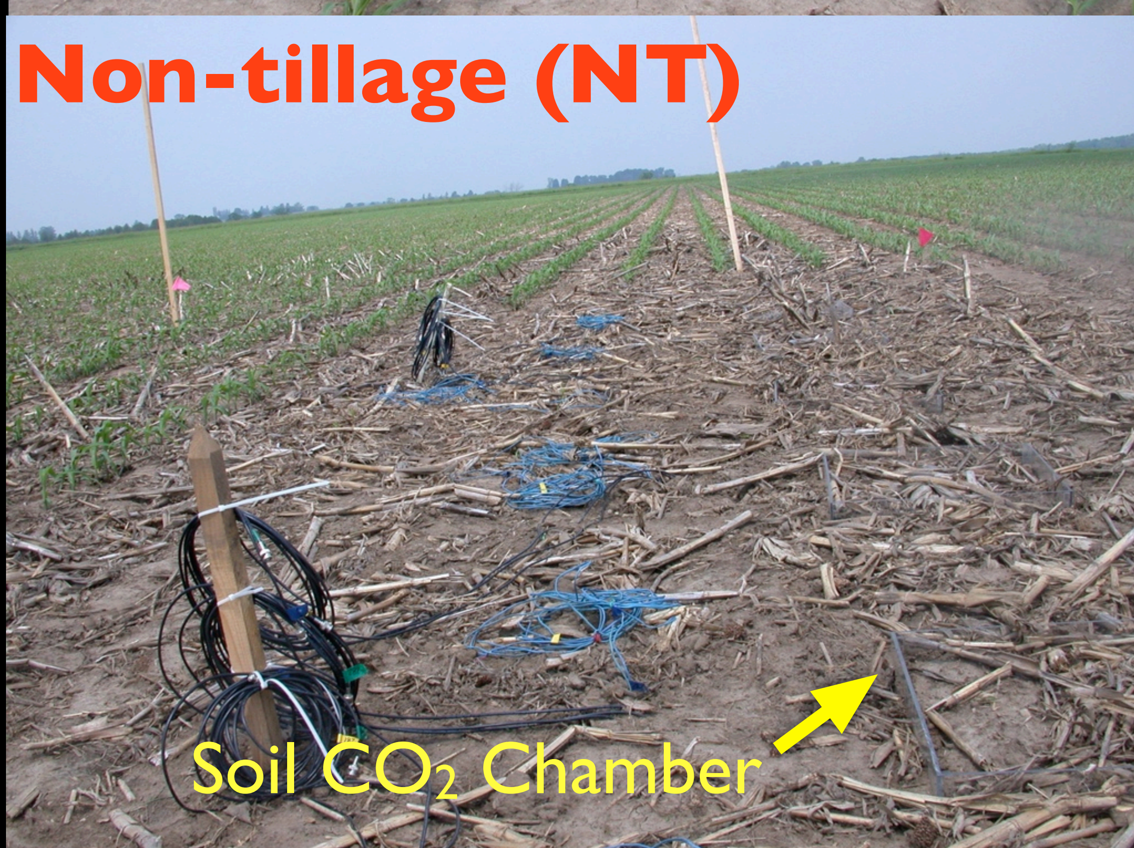
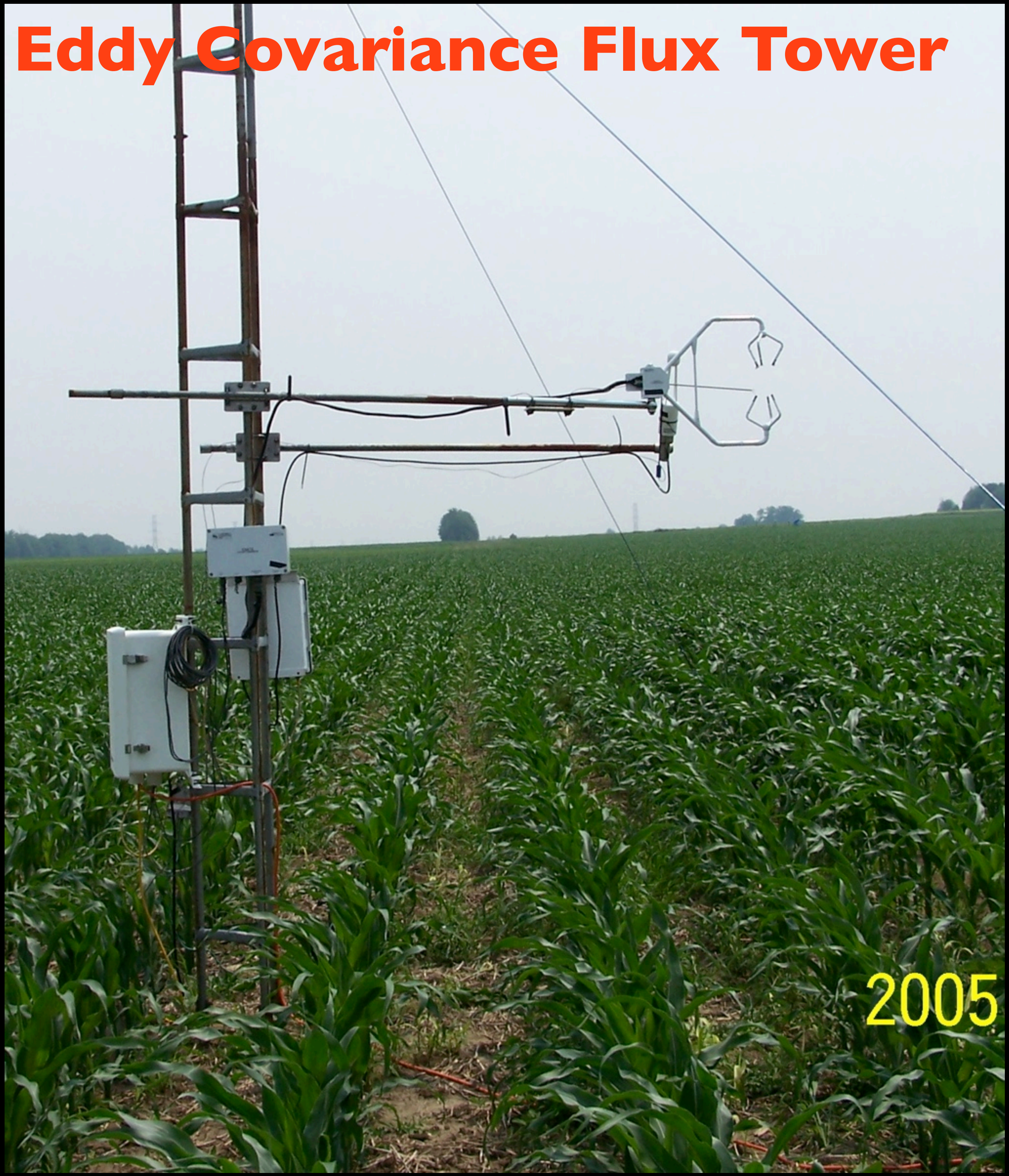




Measuring Ecosystem CO_2 Fluxes



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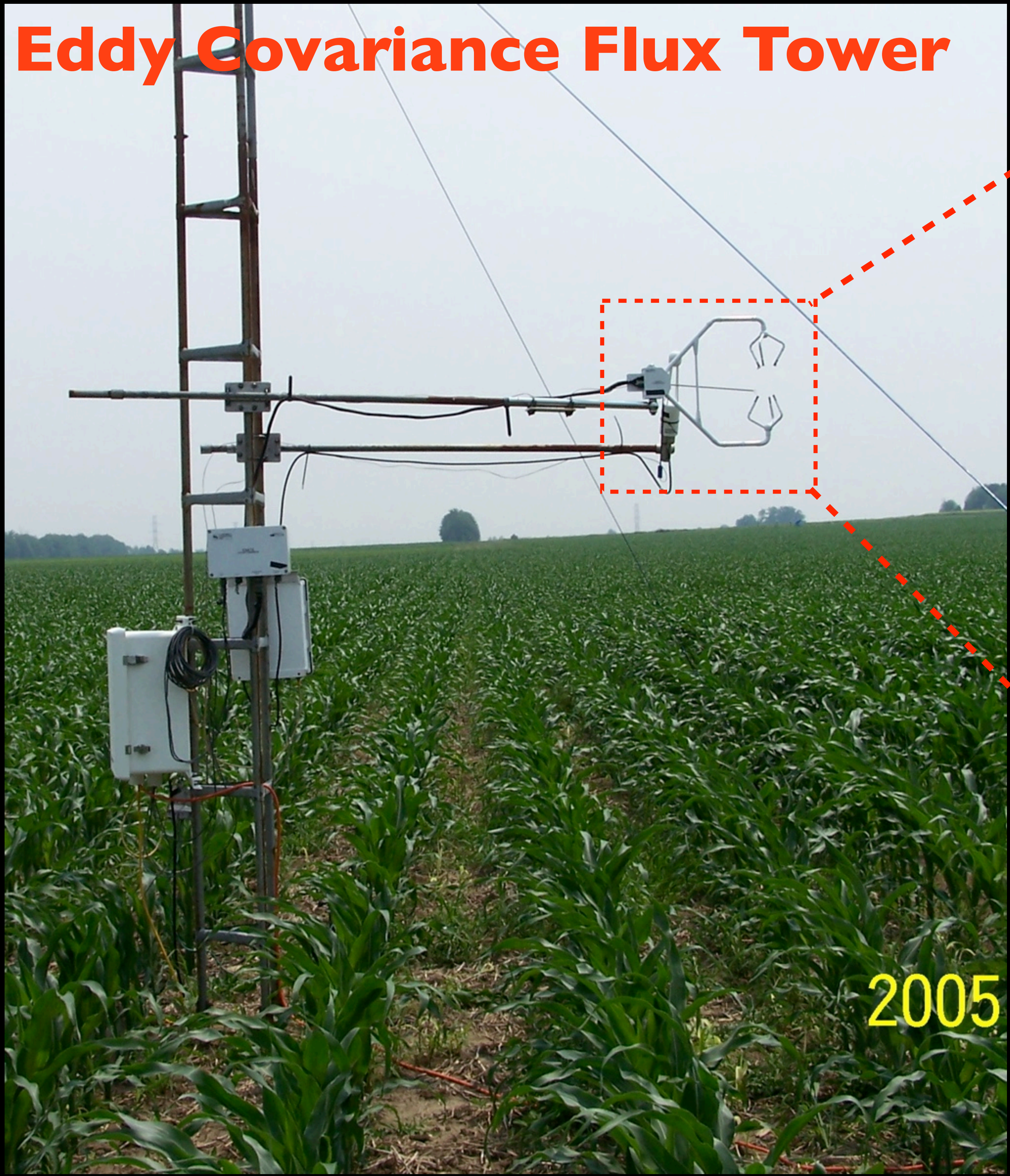

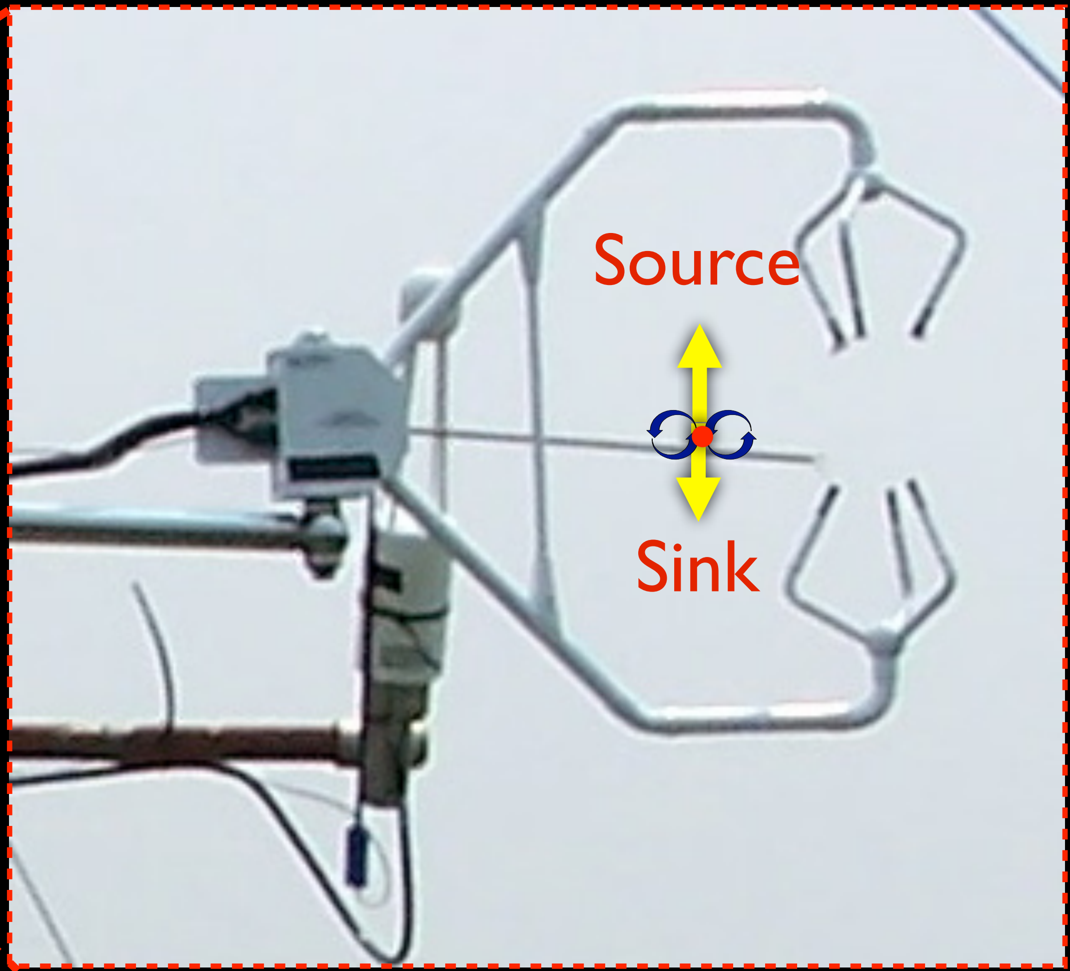

Modeling Carbon Cycles in Agriculture

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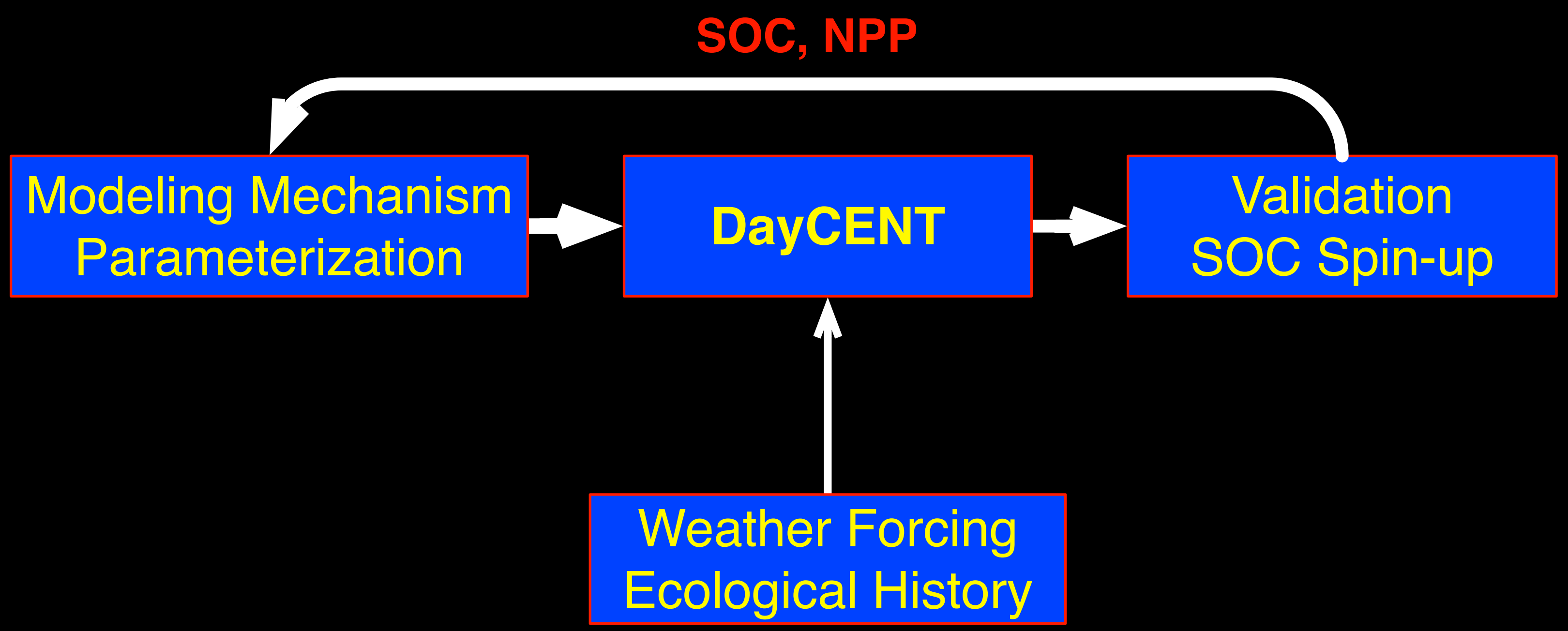
Approaches:

(1) 5000-year SOC equilibrium spin-up

(2) Best Management Practice schedule & Growing Degree Day module

(3) 9-year CT & NT simulation



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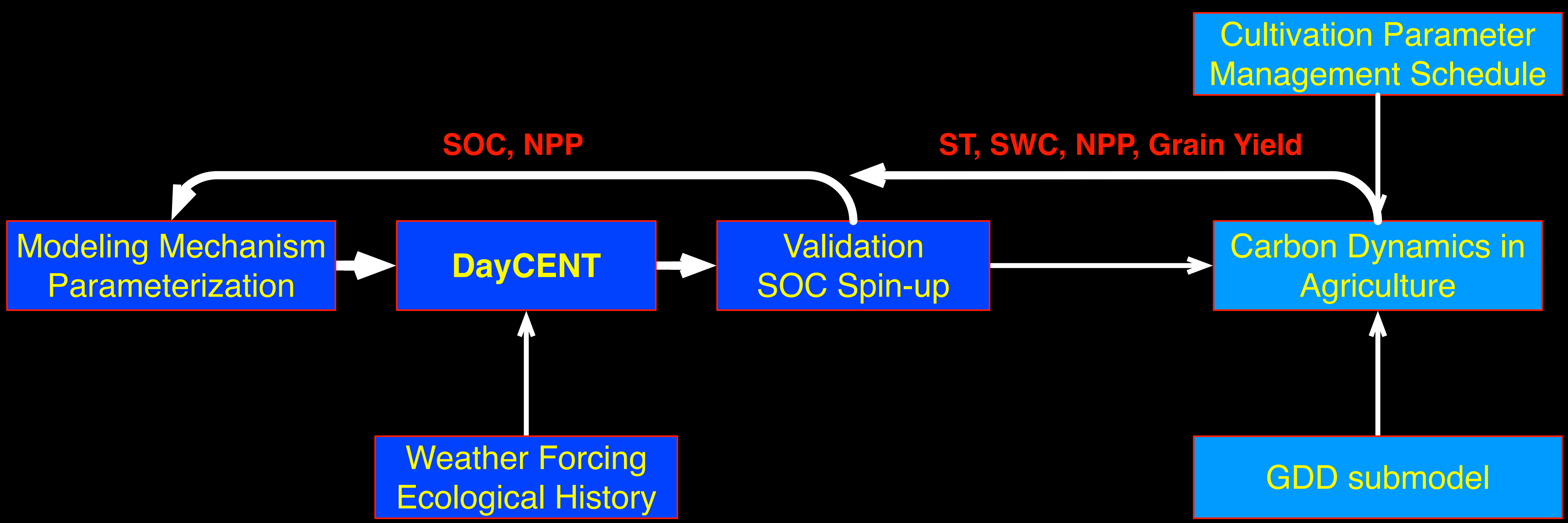
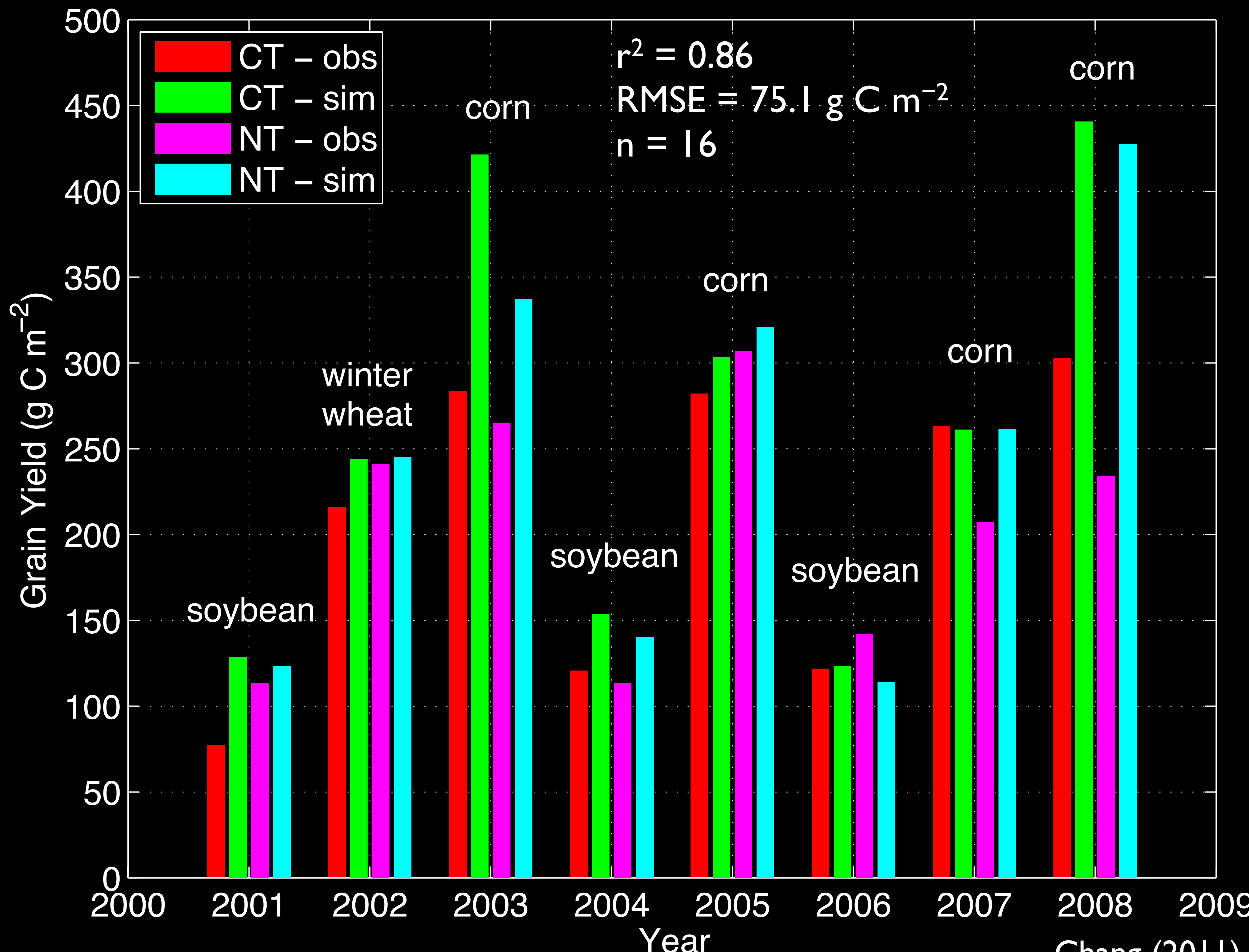
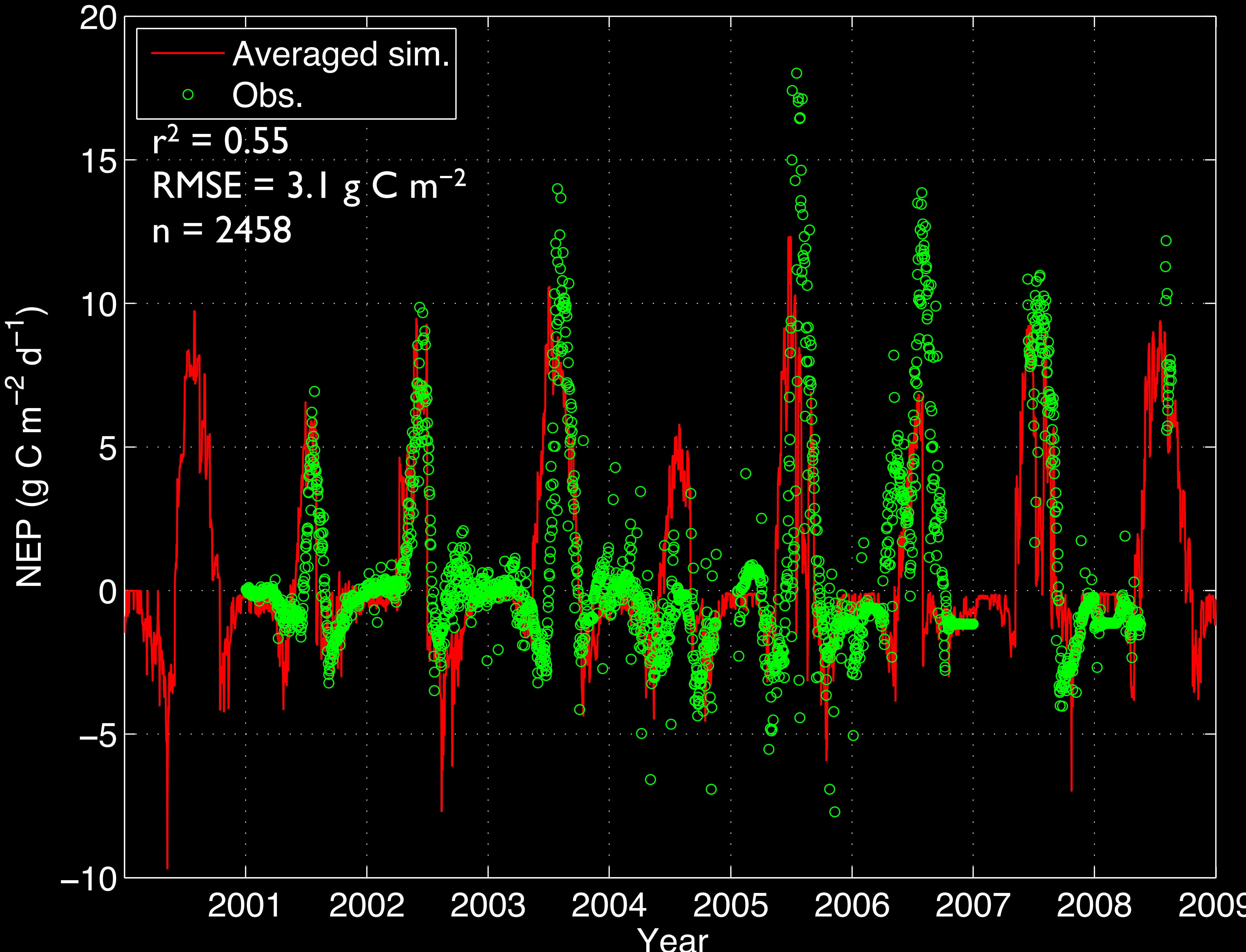


Grain Yield



Chang (2011) *in review*

Simulated NEP vs. Eddy Covariance Carbon Flux



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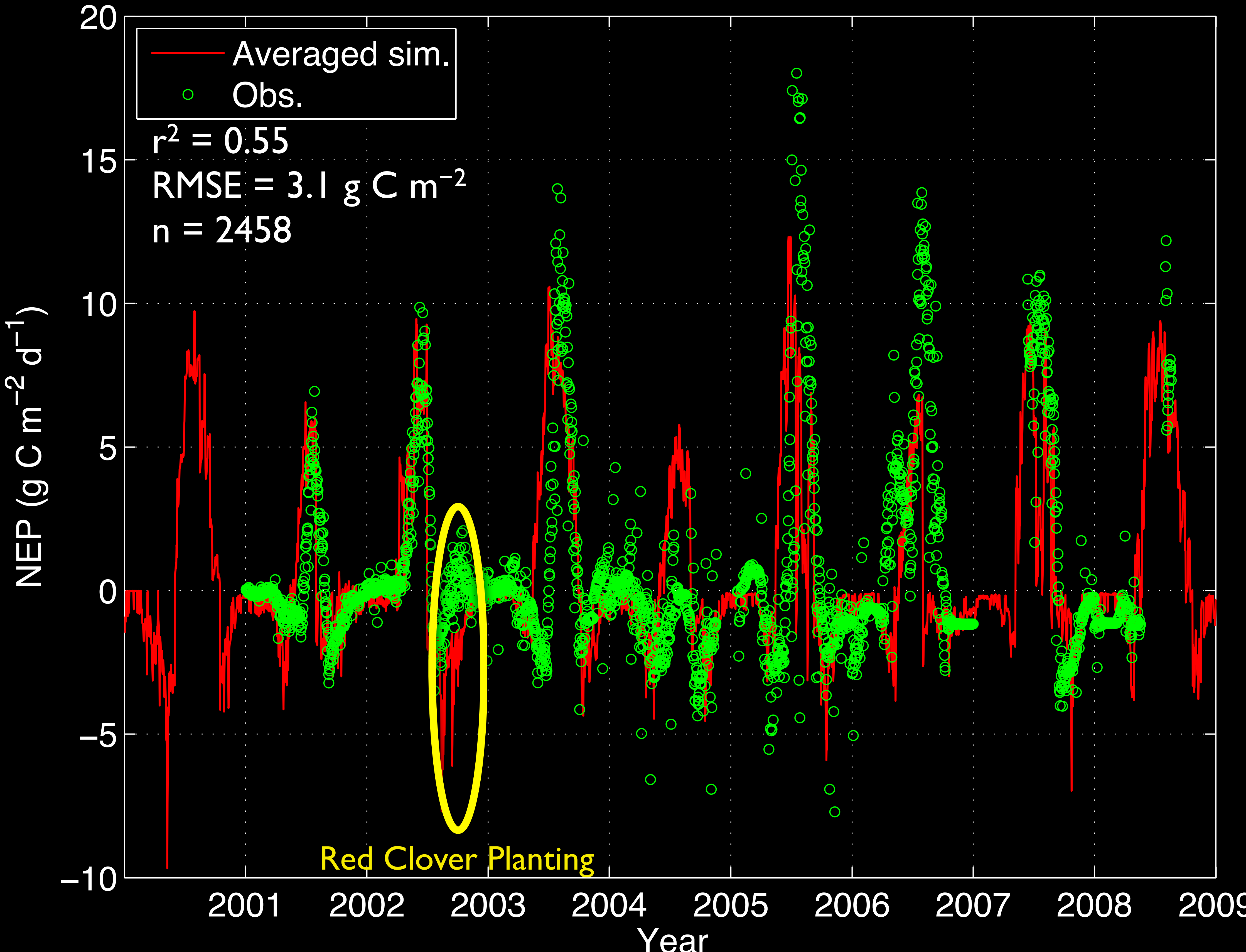

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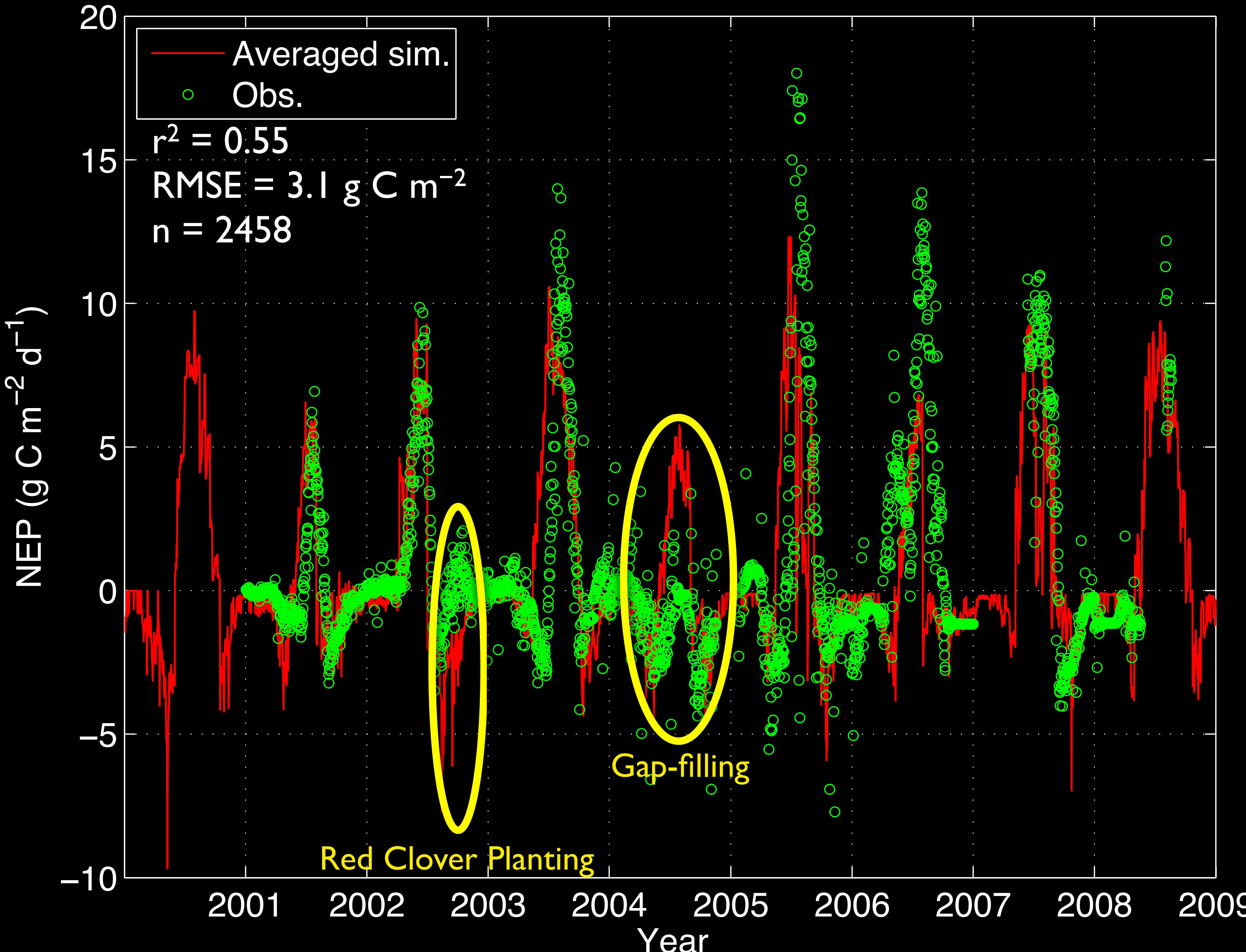
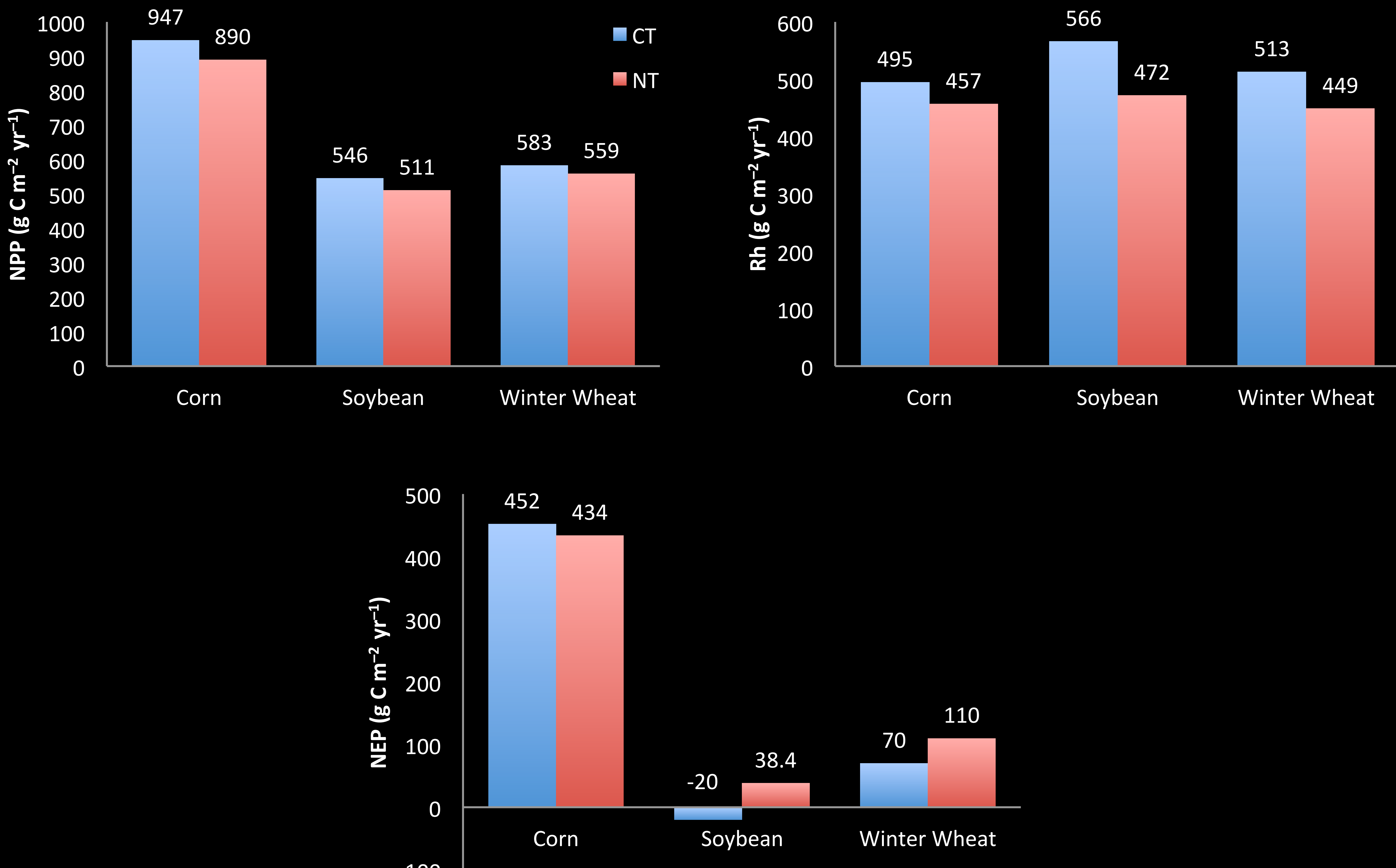
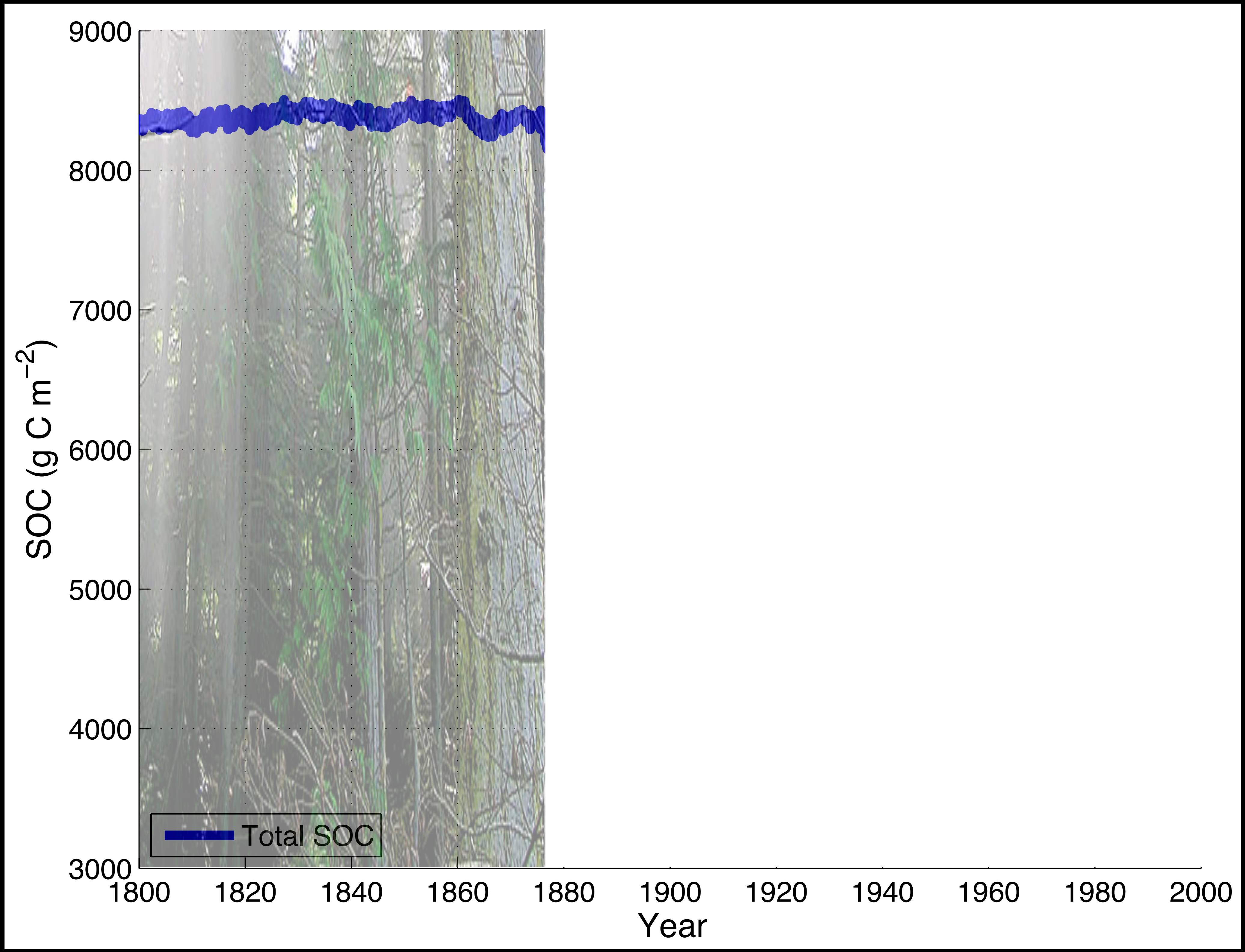


Summary : Tillage Effect on NPP/Rh/NEP



Long-term SOC dynamics



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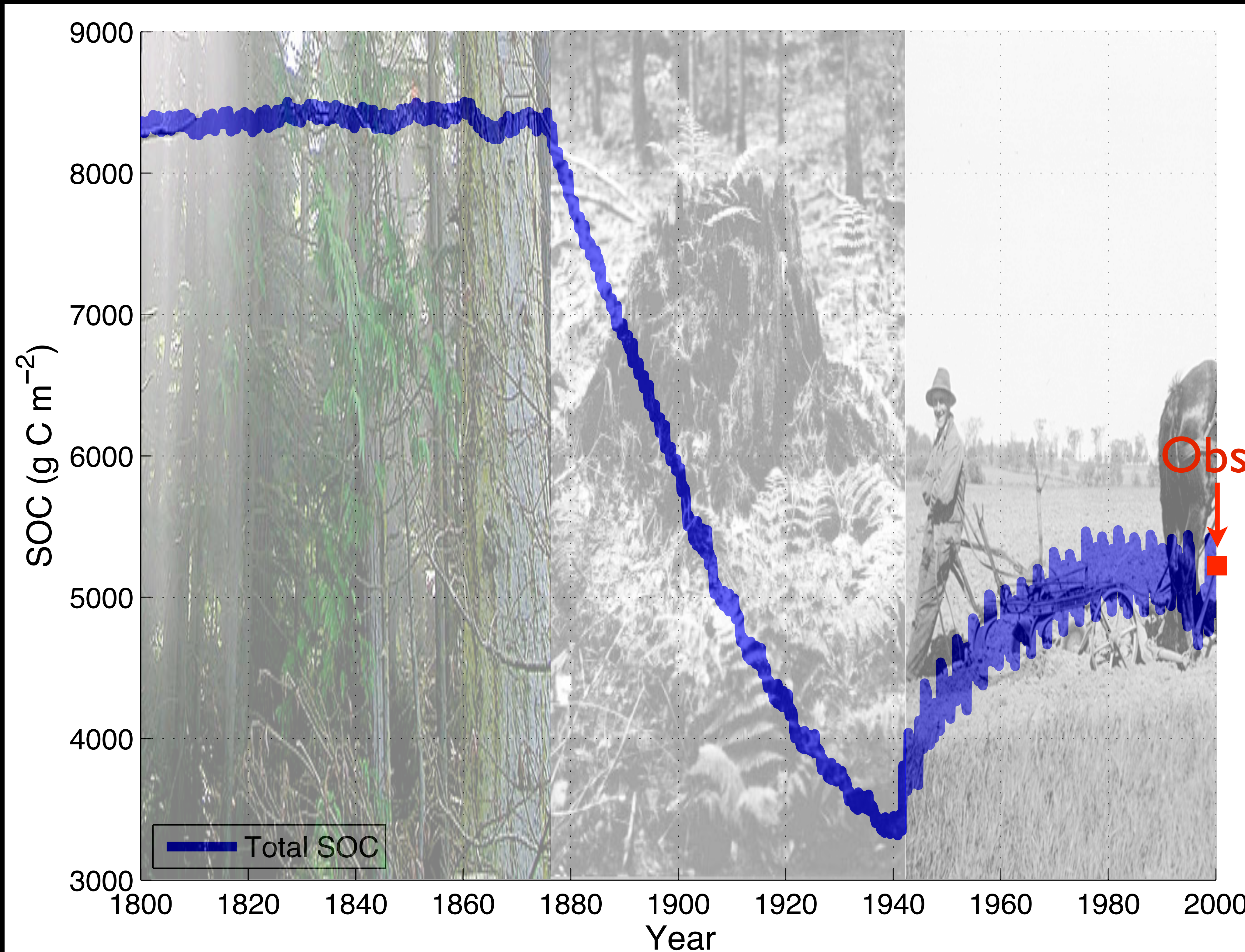
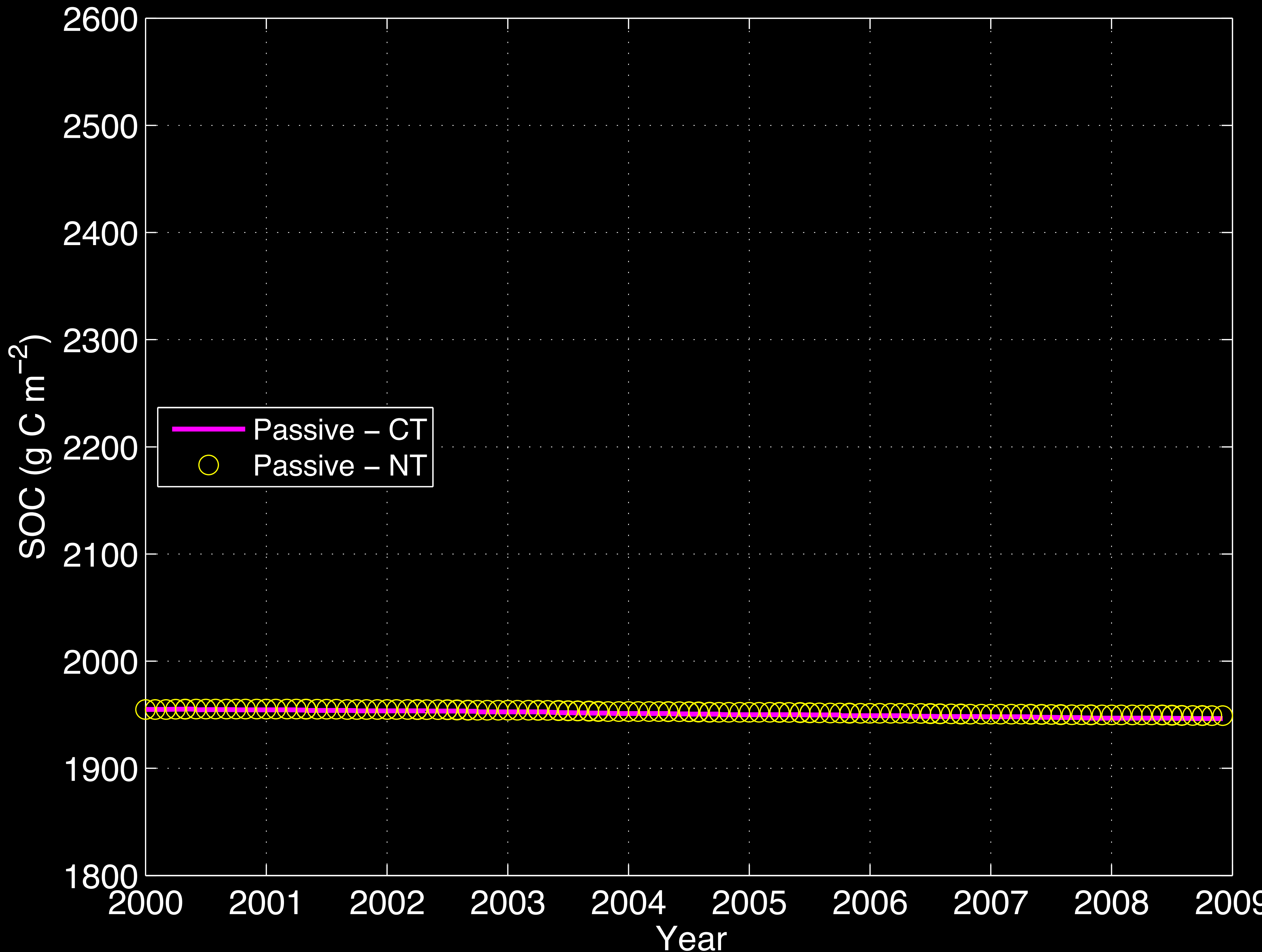


Tillage effect on Slow & Passive SOC Dynamics



Tillage effect on Slow & Passive SOC Dynamics

Modeling Crop Phenology in CN-CLASS

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Model doesn't work !!

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, G00H05, doi:10.1029/2009JG001229, 2010

A model-data intercomparison of CO_2 exchange across North America: Results from the North American Carbon Program site synthesis

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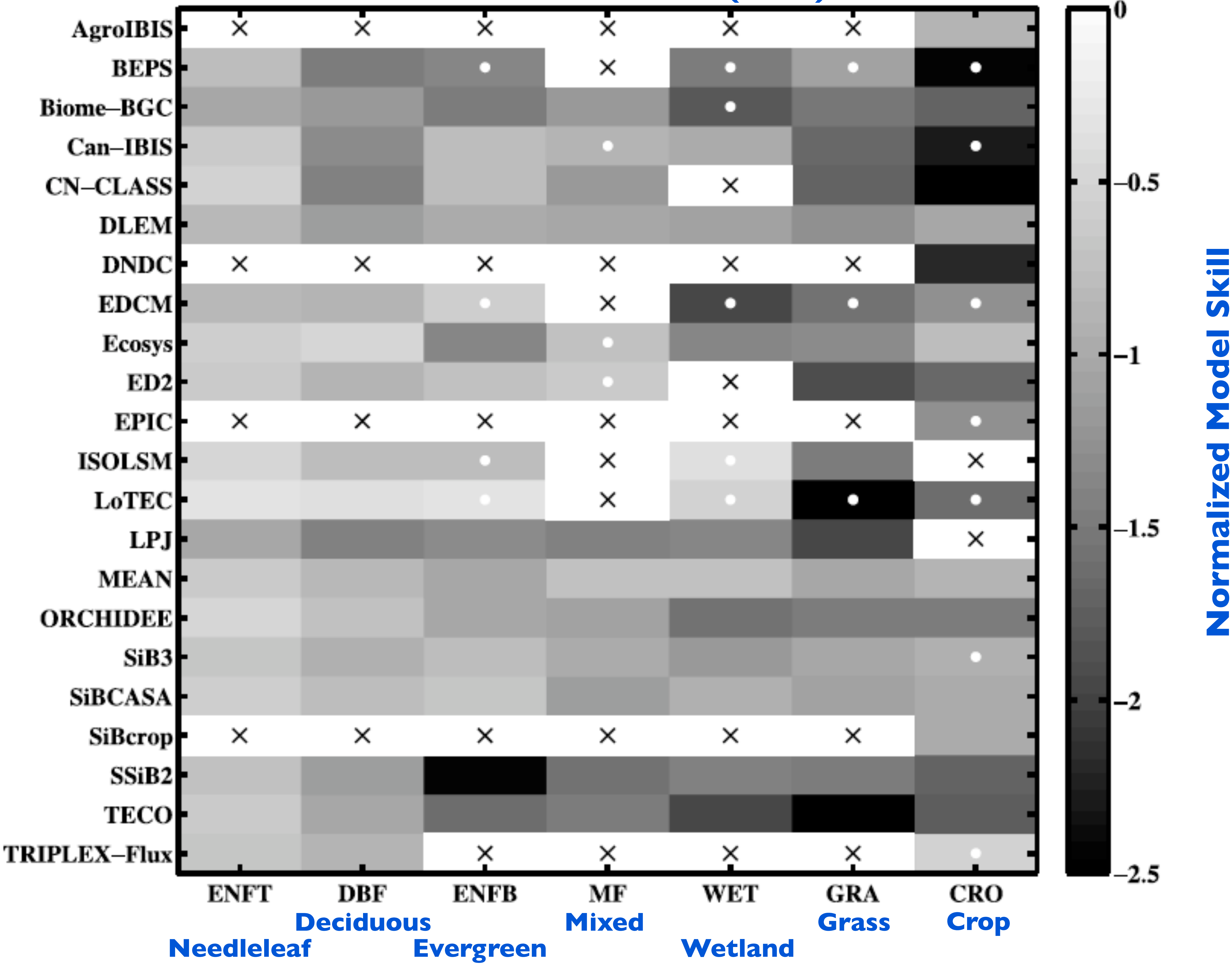
Monday, August 8, 11

Model Skill Metrics For All 21 Models – NEP Simulation

Schwalm et al. (2010)



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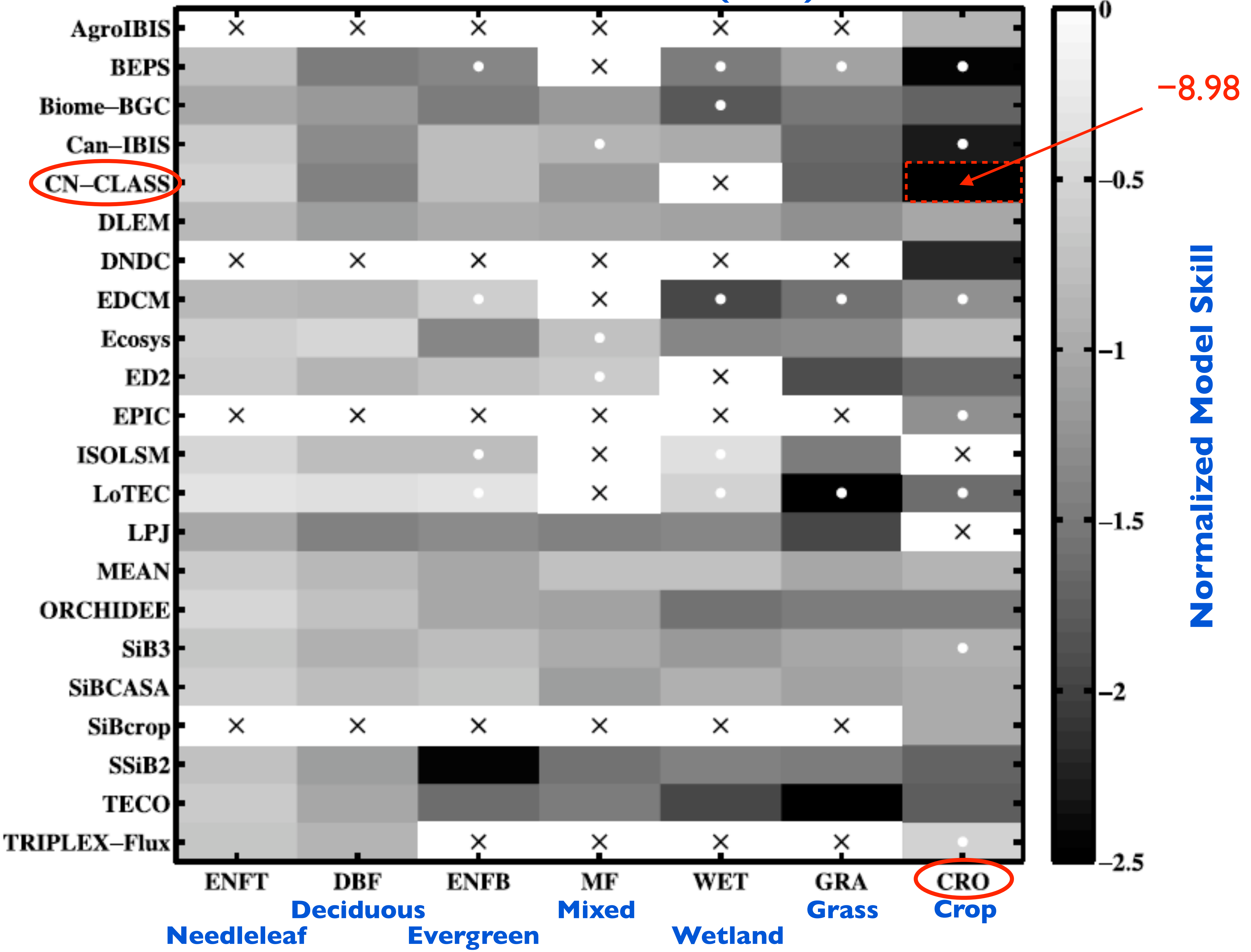

Differences of Modeling between Crops and Forests

Crops differs morphologically and physiologically from forest.

- Photosynthetic efficiency
- Phenological development
- Carbon allocation

New corn roots and leaf

New tree leaf

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Crops differs morphologically and physiologically from forest.

- Photosynthetic efficiency
- Phenological development
- Carbon allocation

→ Affect the climate by modifying carbon exchange

New corn roots and leaf

New tree leaf

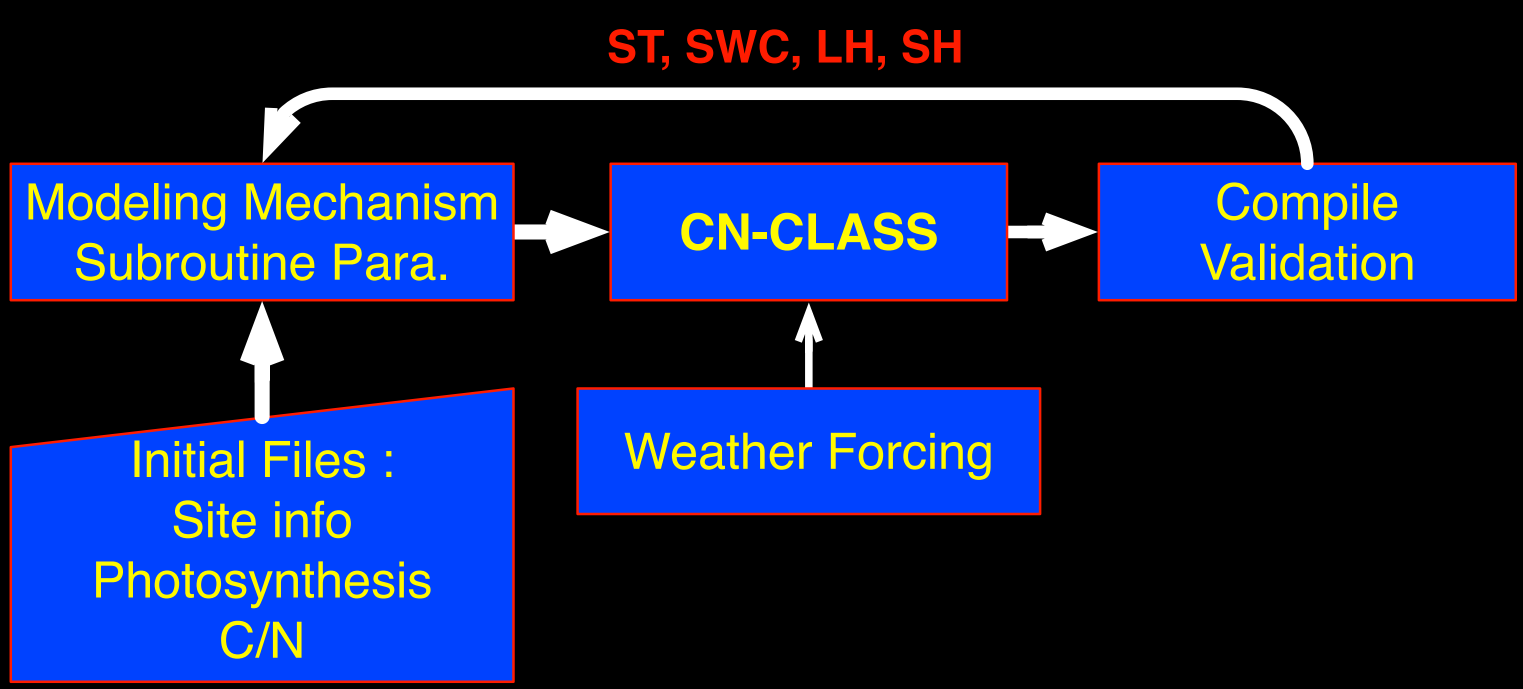
Improving Crop Phenology in CN-CLASS

Approaches:

(1) Debugging & parameterization for water/energy balance

(2) New algorithms for agricultural simulation

(3) Model verification with DayCENT and measurements.



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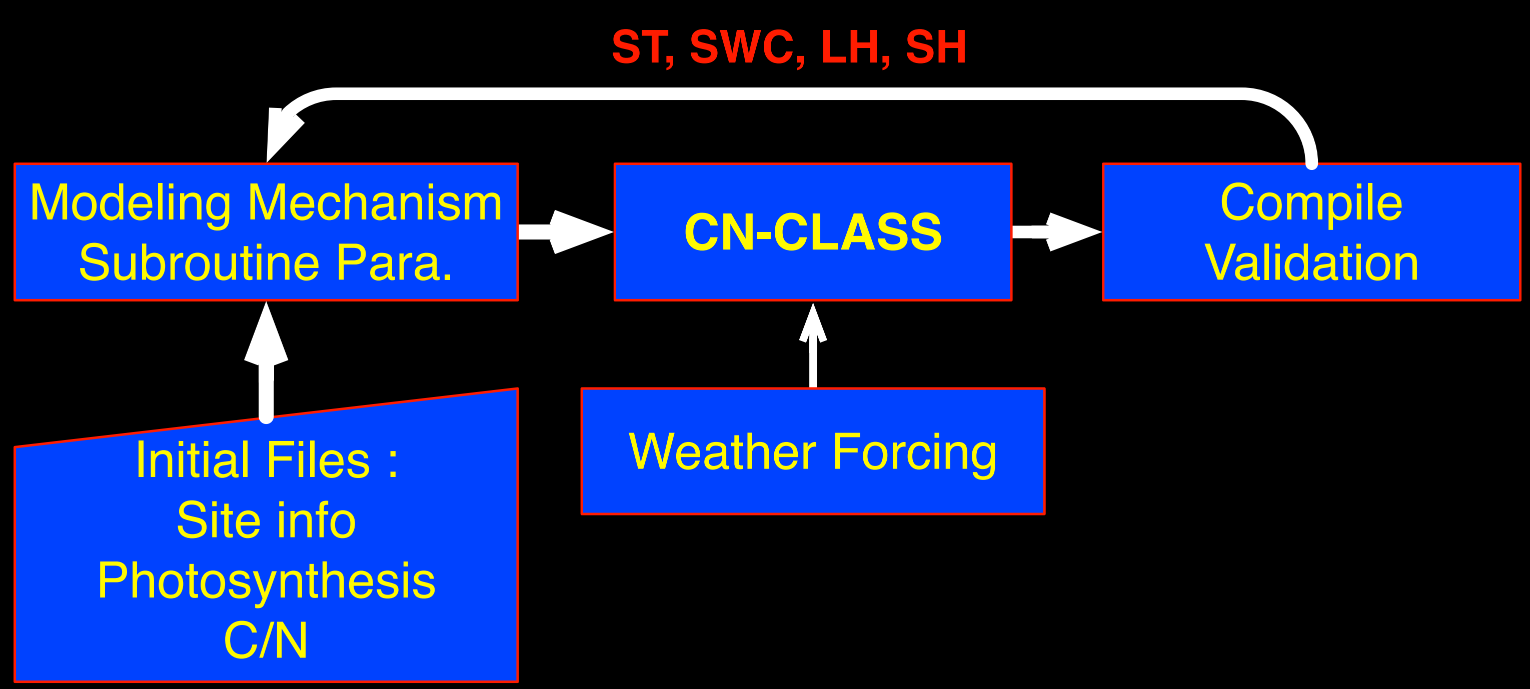

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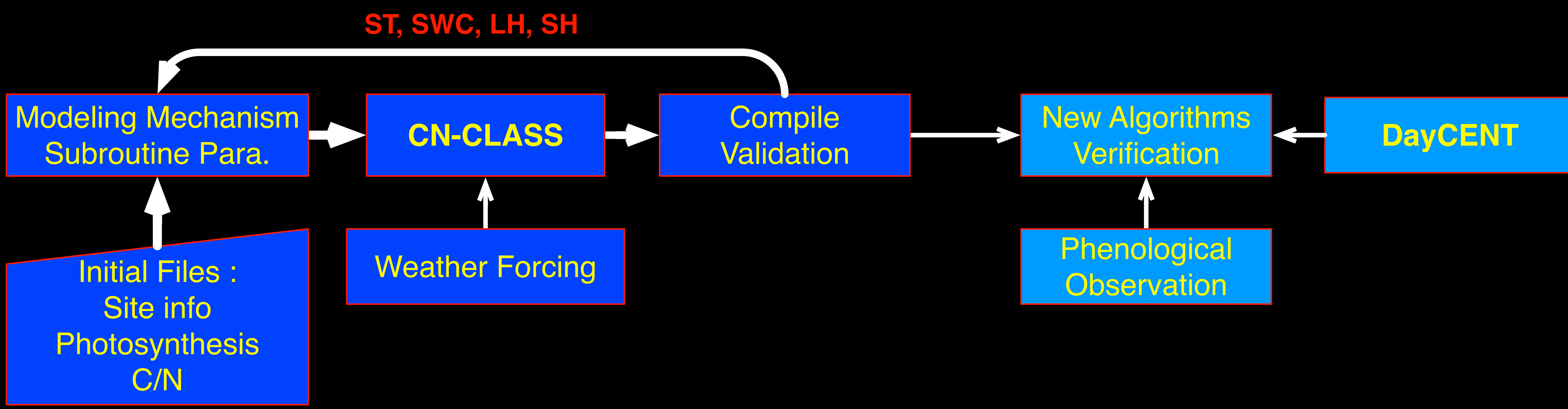
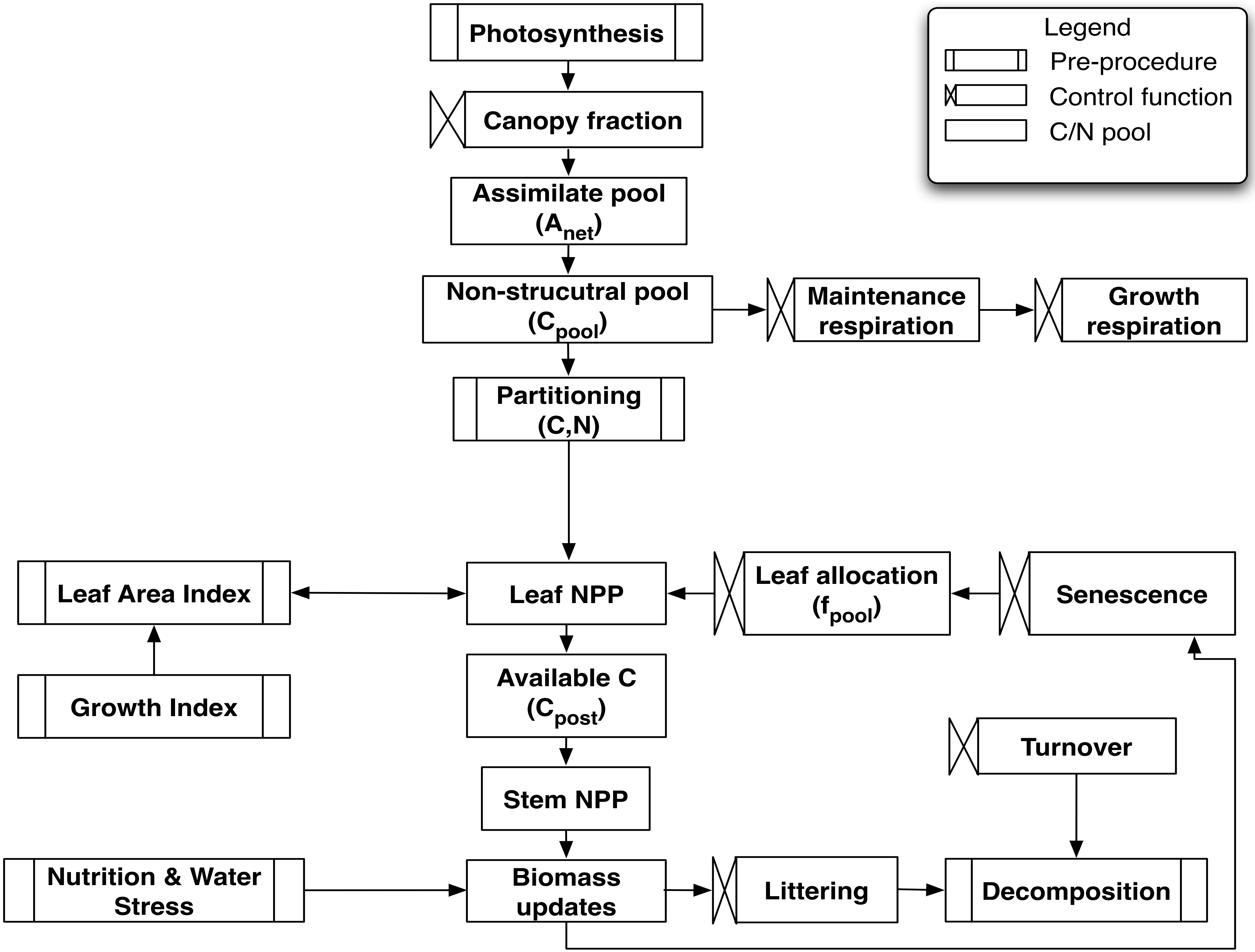


Carbon Subroutines in the Original CN-CLASS



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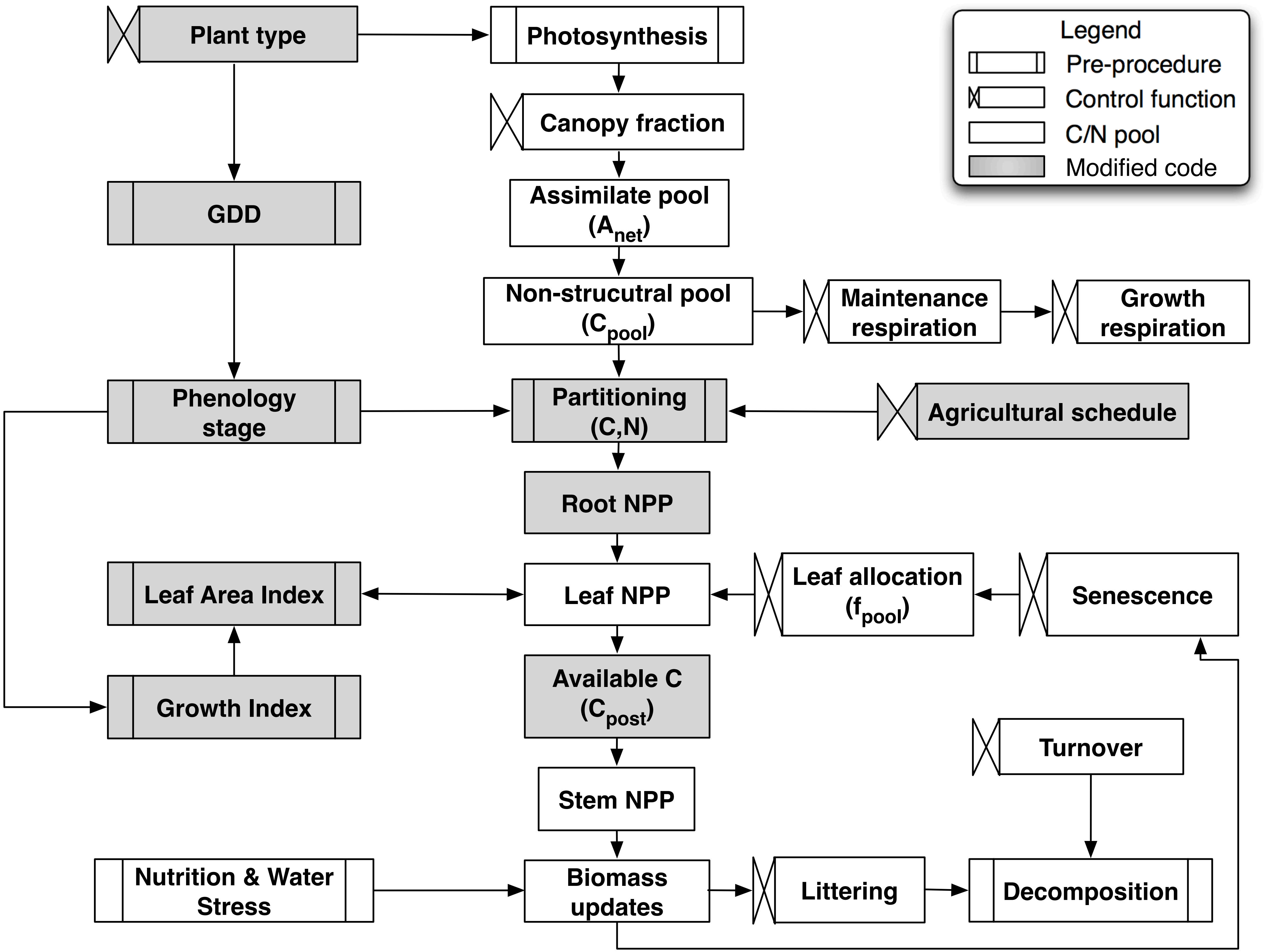

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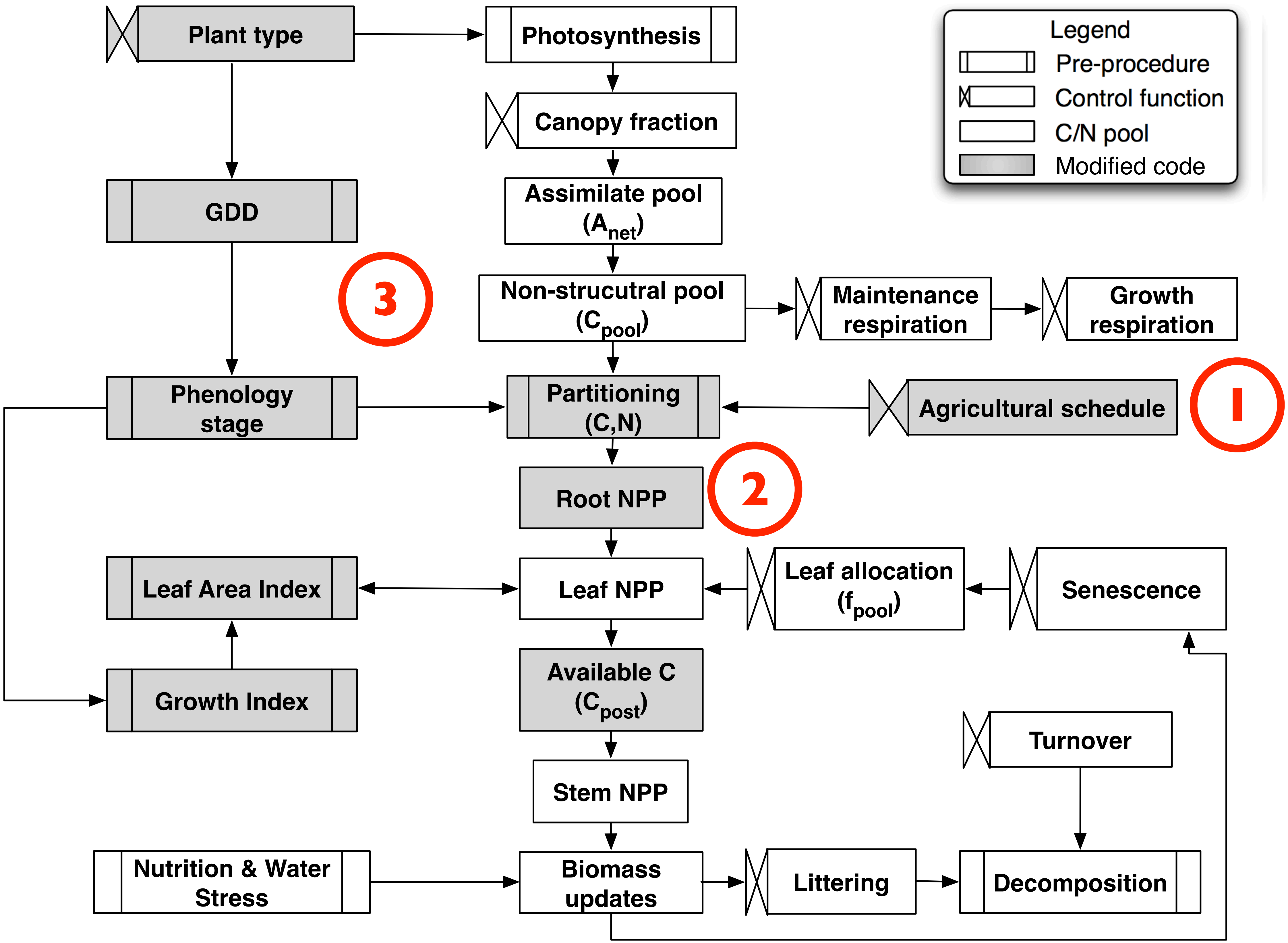
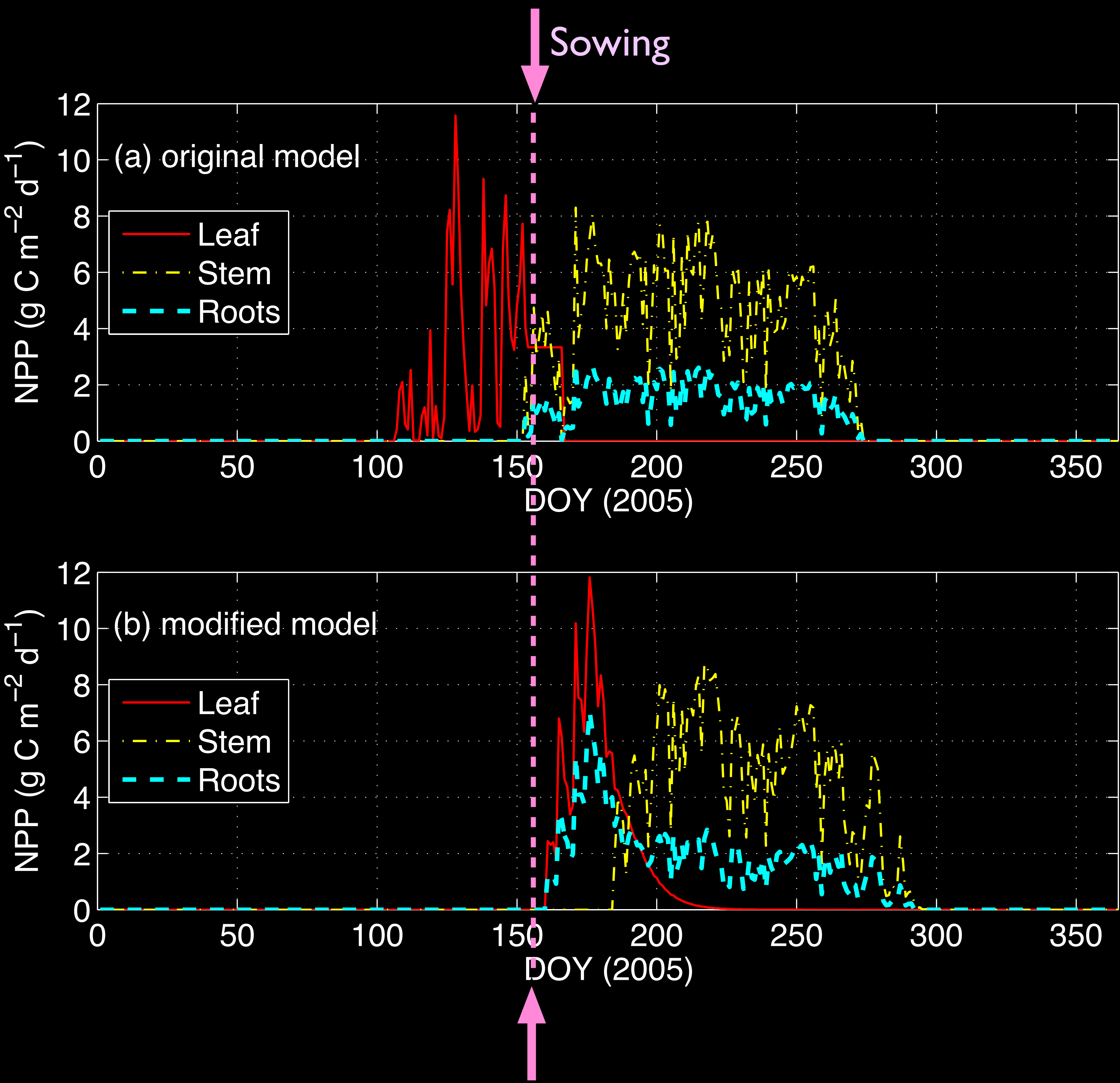


Modeling Diagnosis and Modification



The original model operated using:

- Global growing season algorithm
- Carbon allocation for forests

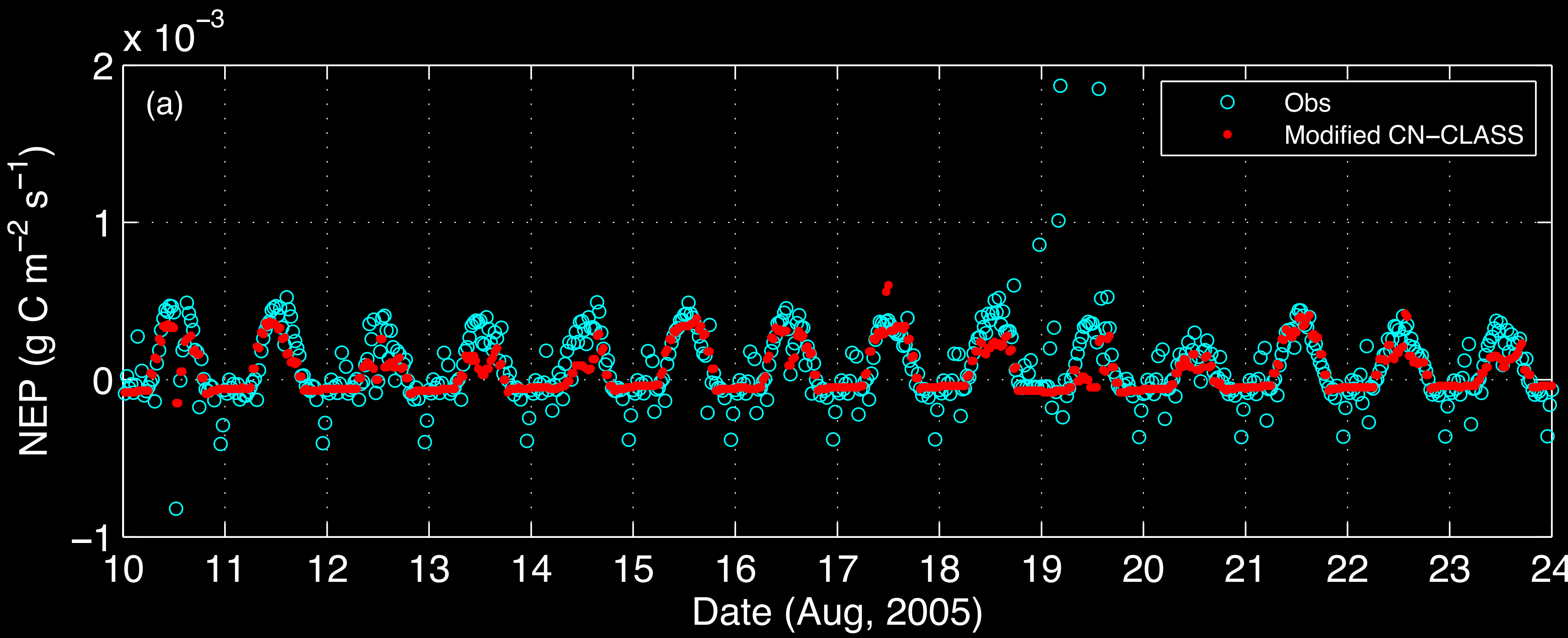
The improvement approached by:

- Agricultural schedule
- Crop-specific phenology

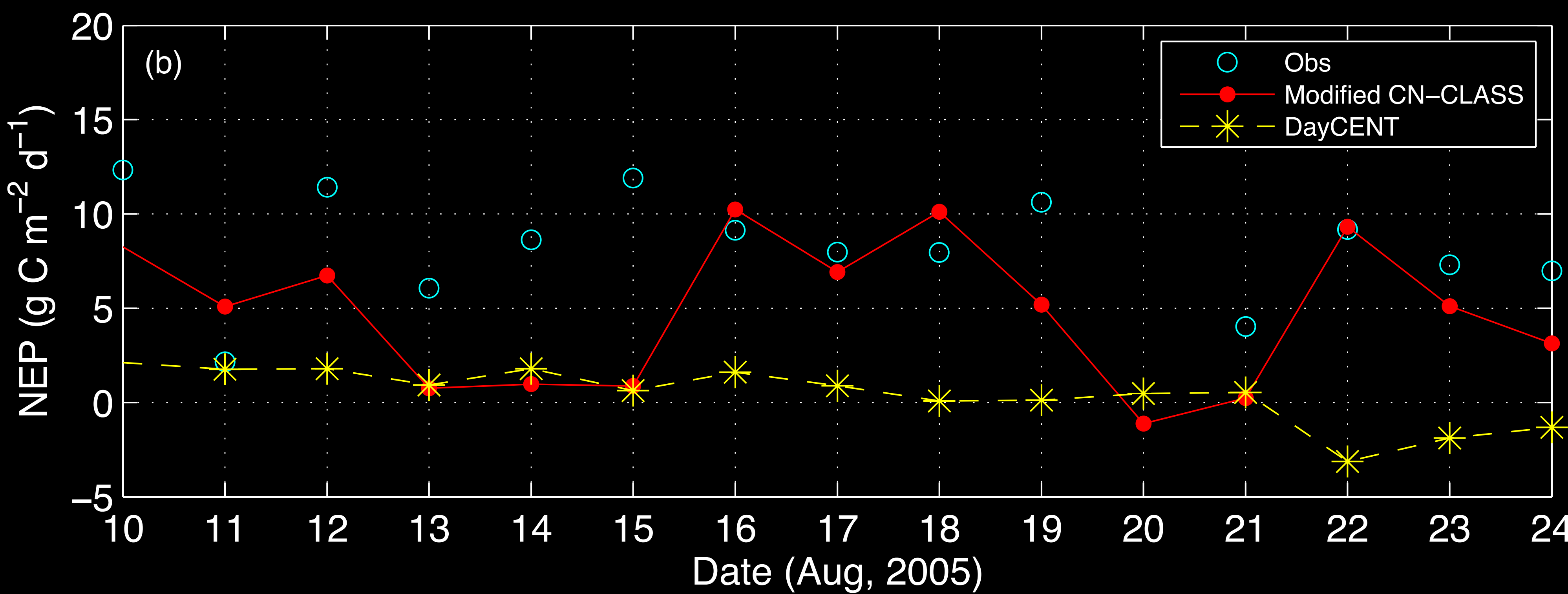
Chang (2011) *in review*

14 Days NEP Tendency

Half-hourly



Daily



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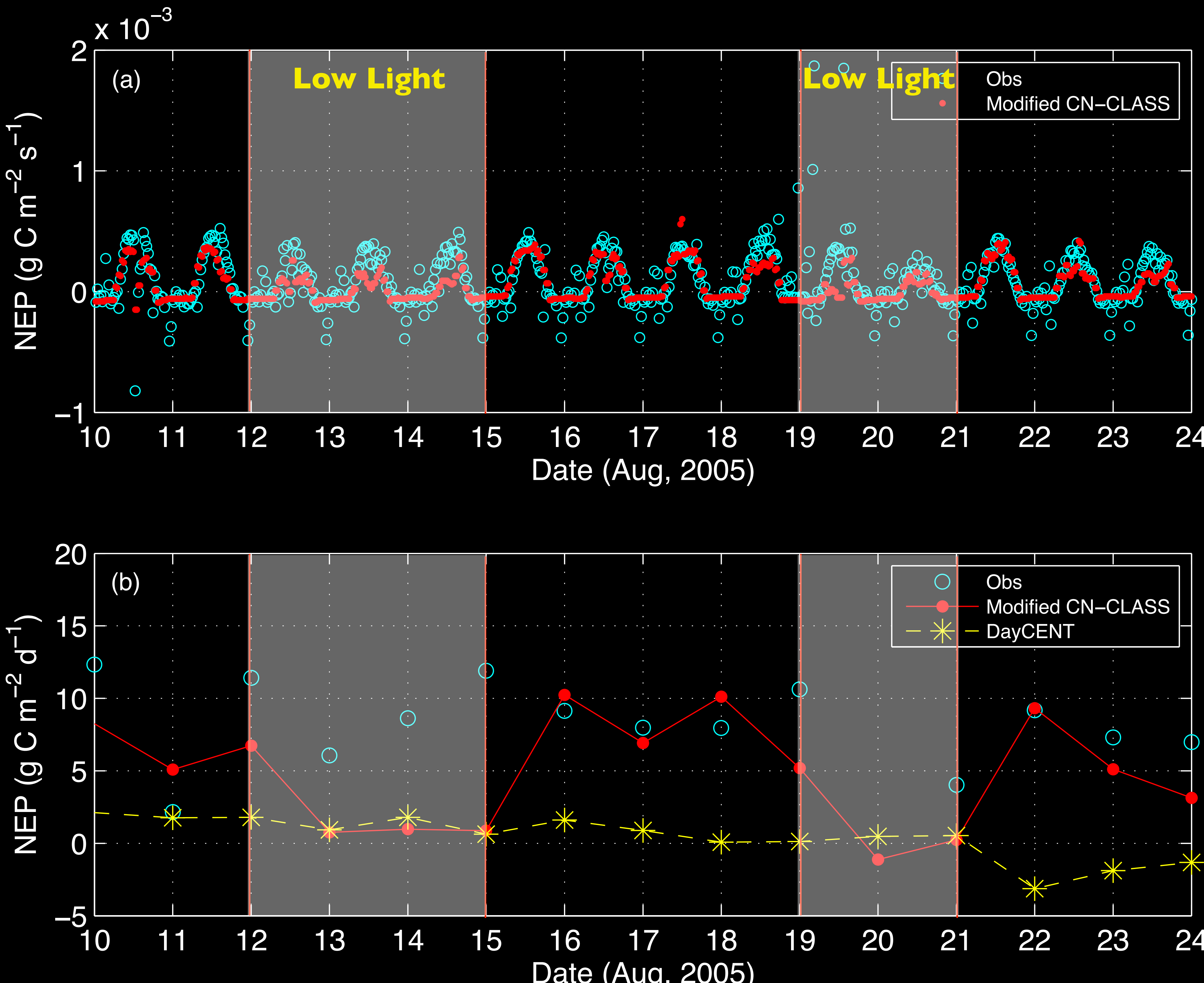
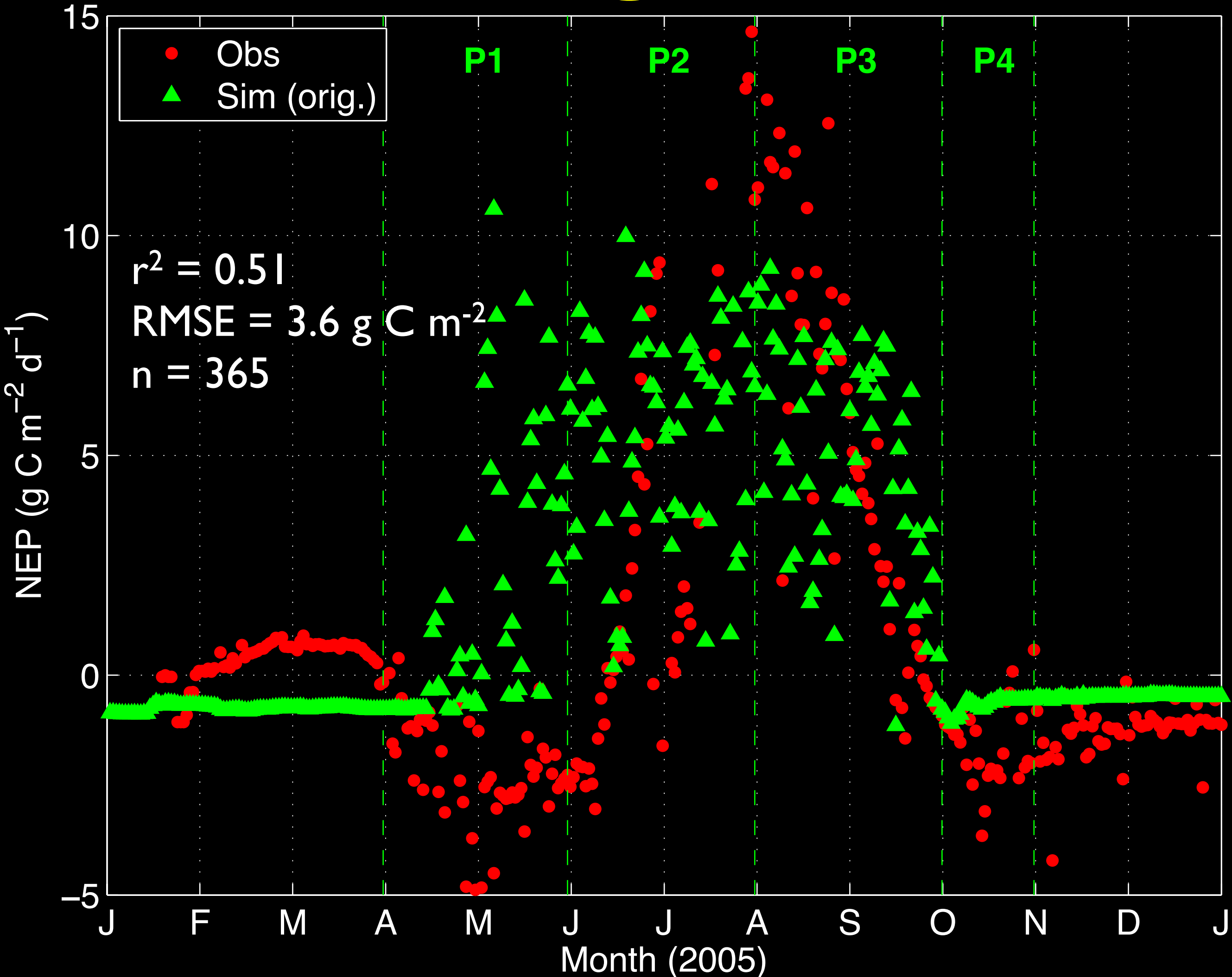
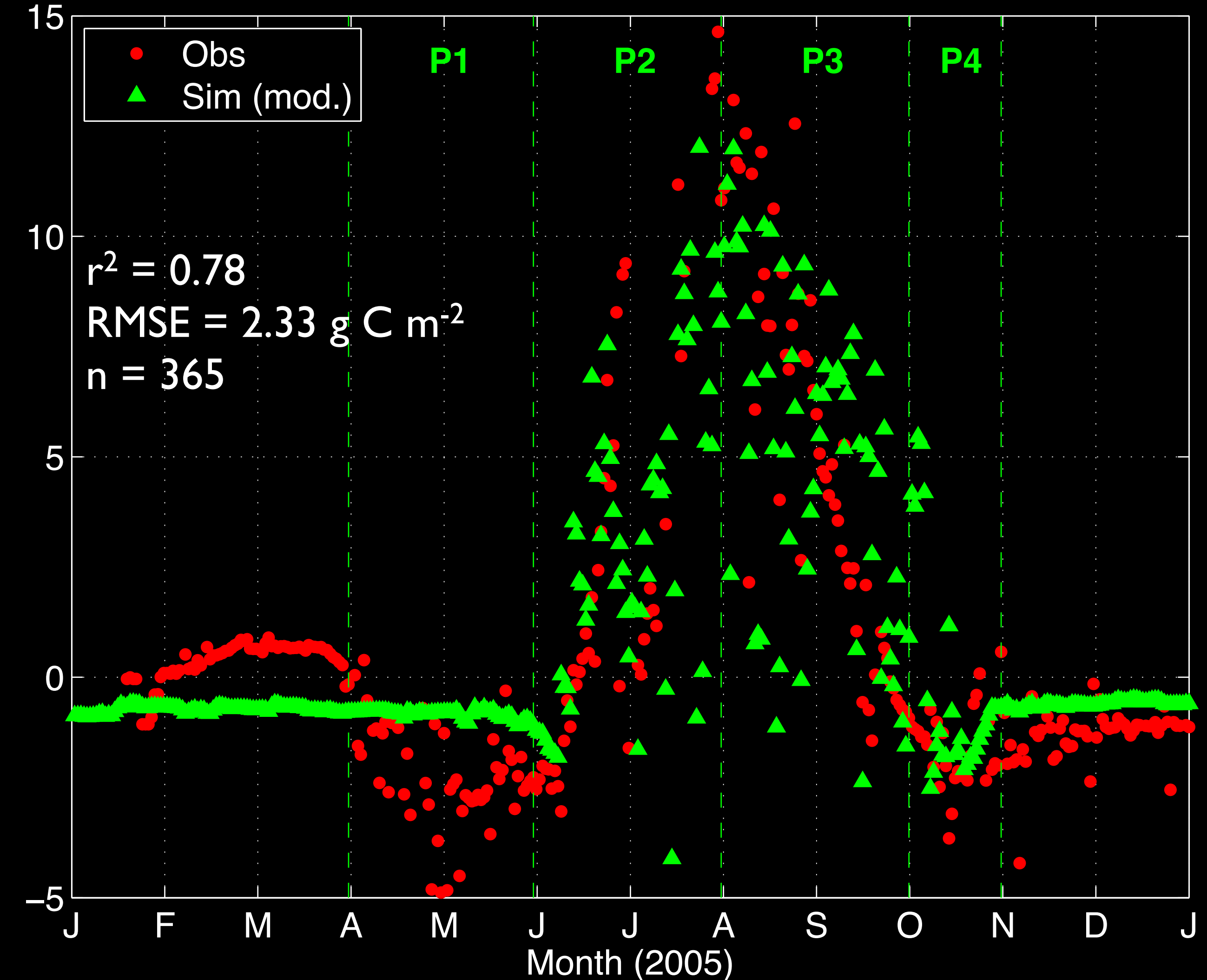


Importance of Crop Module in Land Surface Model

Original



Modified



The comparison suggested that:

- Our modification improves cropland simulation using CN-CLASS
- Crop phenology needs to be taken account for carbon assimilation

Improving Respiration Algorithms for Forests

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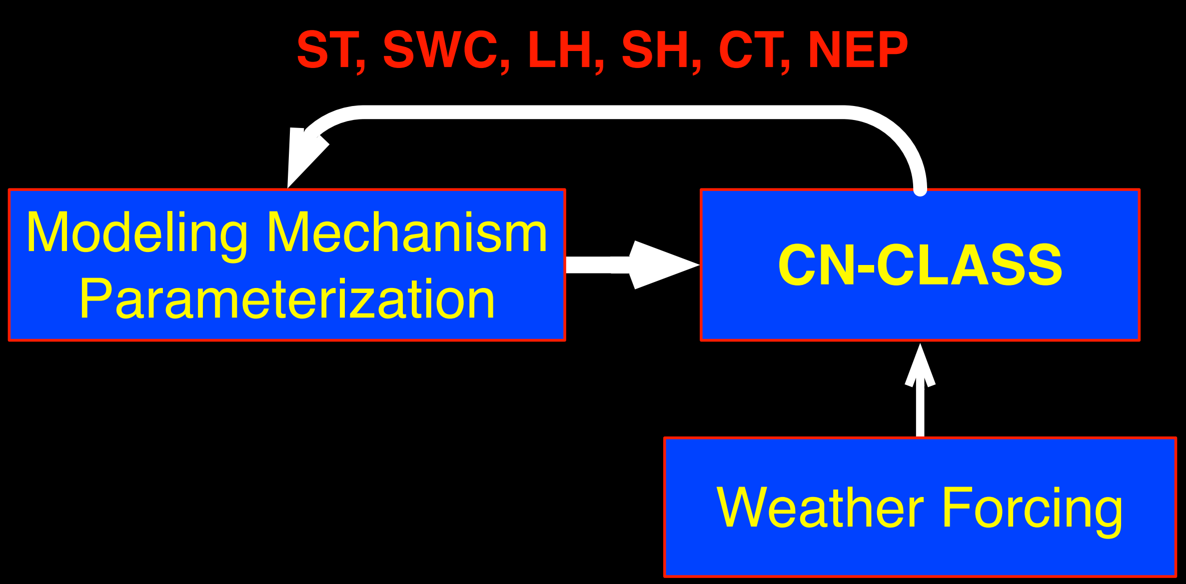
(1) Parameterization and validation for deciduous forests

(2) Improving respiration algorithms based on chamber experiment

(3) Examining phenology and component respiration



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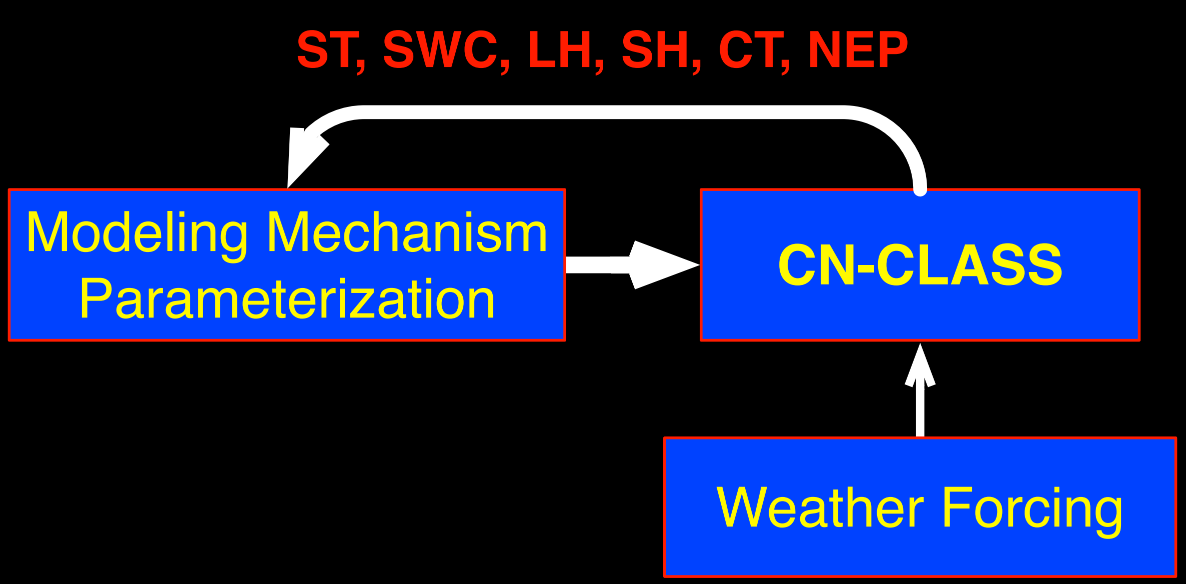


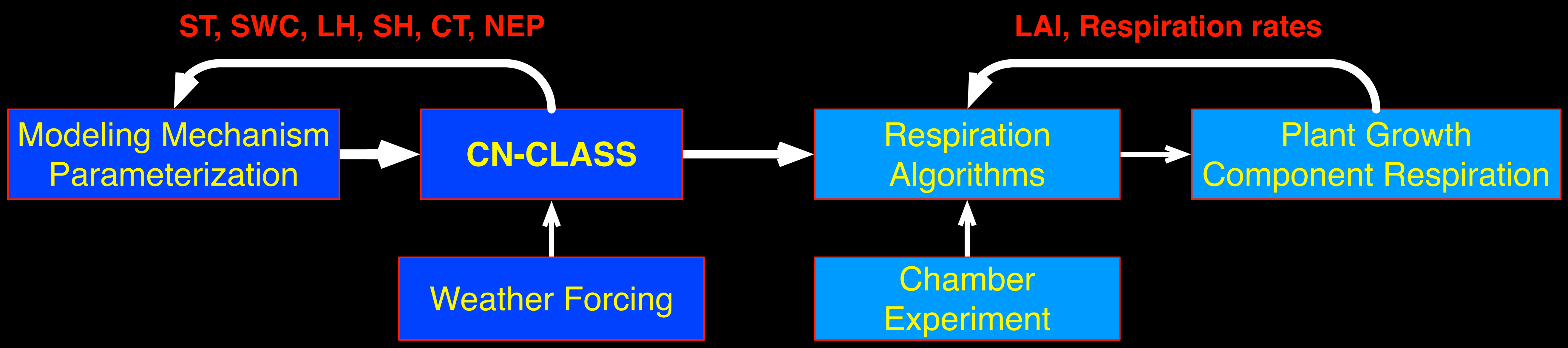
Improving Respiration Algorithms for Forests

Approaches:

(1) Parameterization and validation for deciduous forests

(2) Improving respiration algorithms based on chamber experiment

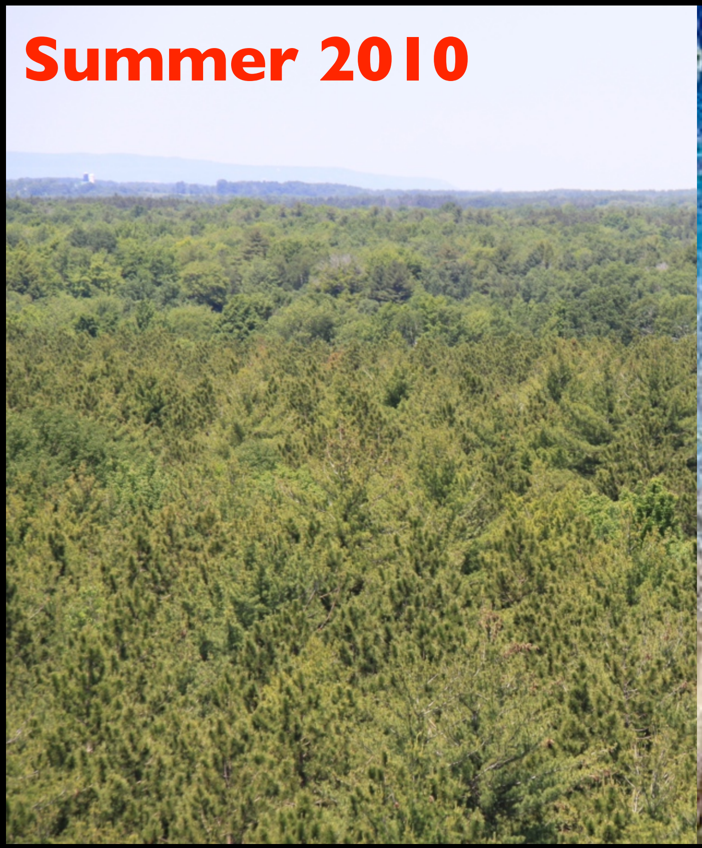
(3) Examining phenology and component respiration



Forest Study Site: Borden

Flux tower height : 40 m
Canopy height : 22 m

Mixed deciduous forests
~120-year old



Soil CO_2 Chamber Experiment in Forests

Fixed soil CO_2 chamber

My foot

Chang (2011) *in review*

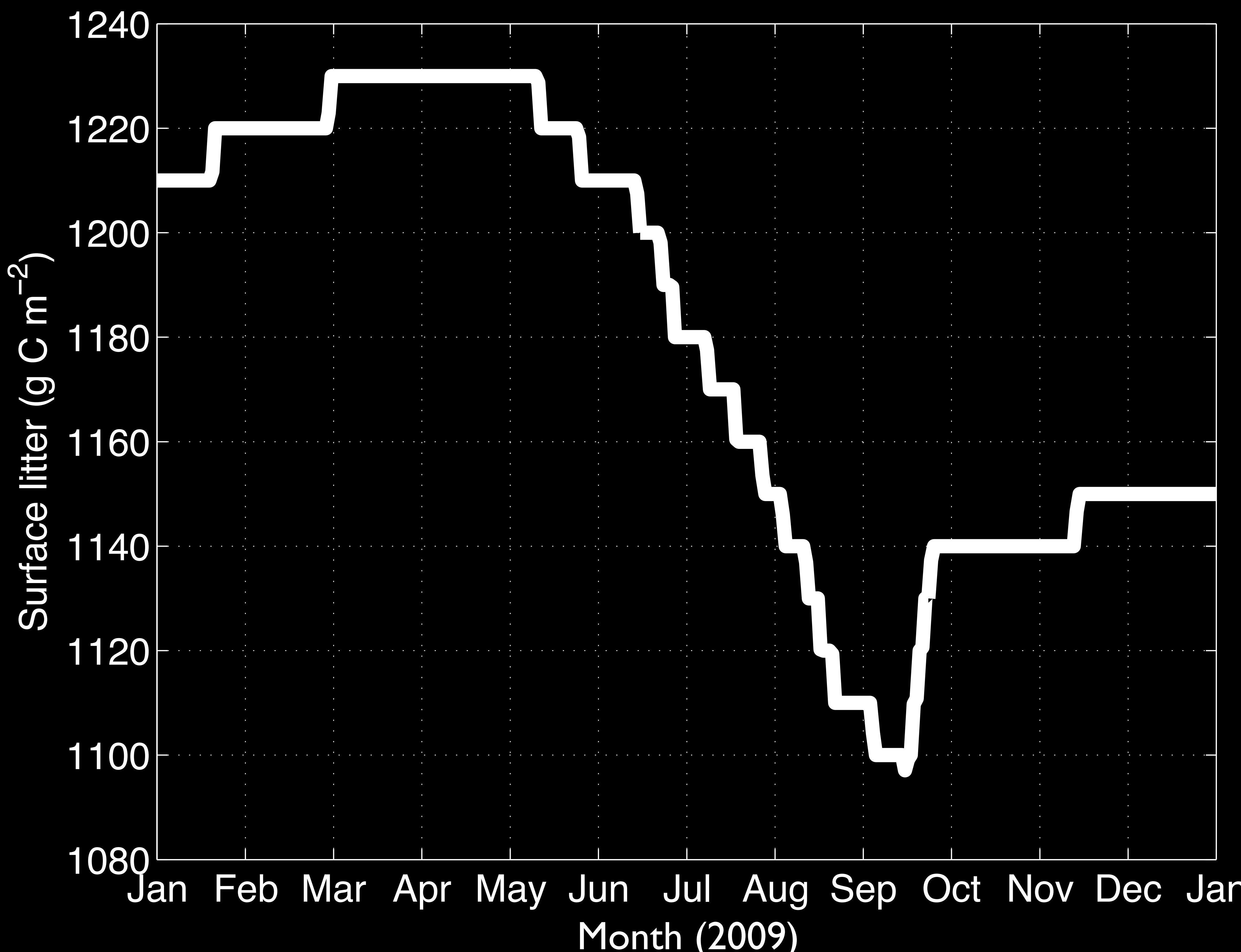
Soil CO_2 Chamber Experiment in Forests

Fixed soil CO_2 chamber

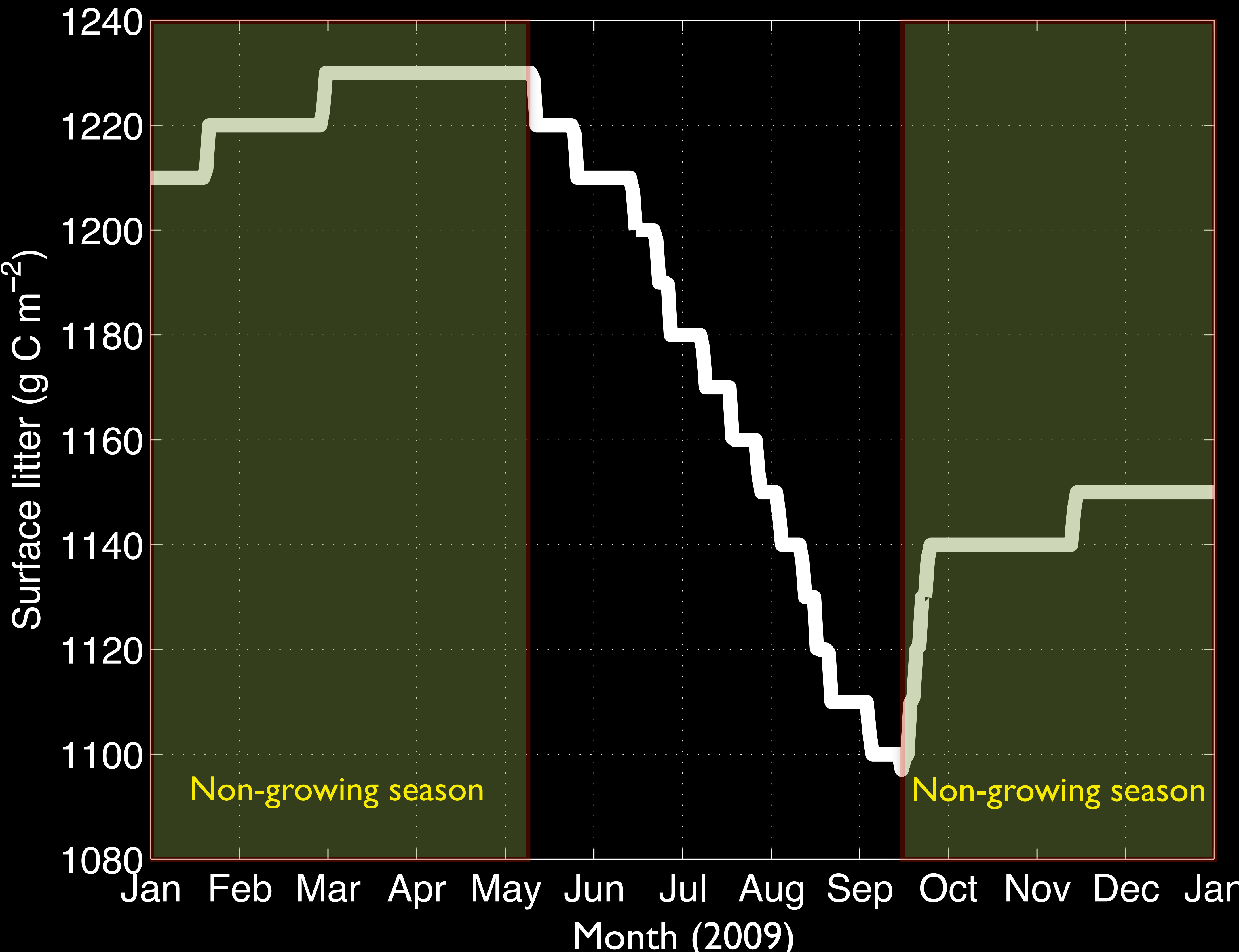
- What is the CO_2 contribution from litterfall ?
- How much litterfall has been decomposed and transformed ?

Chang (2011) *in review*

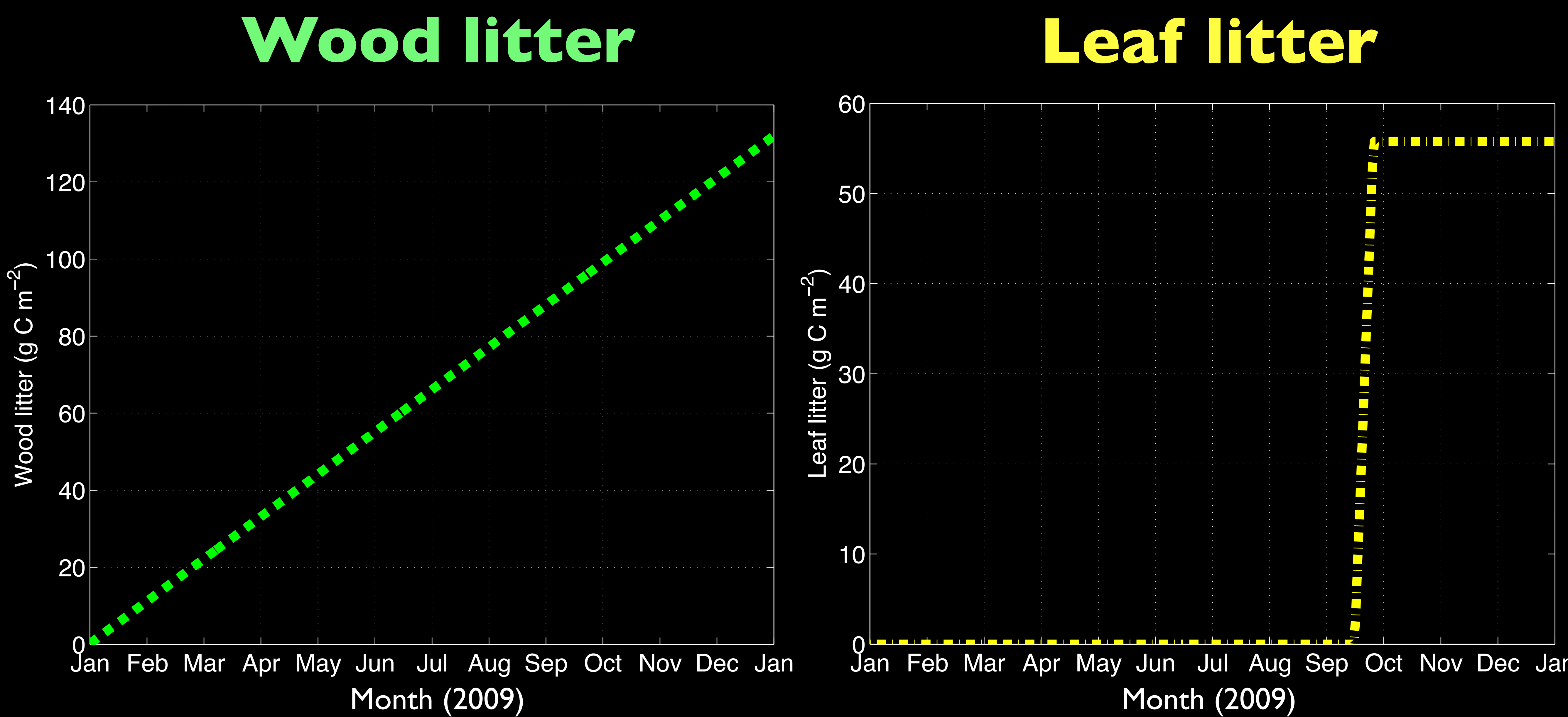
Seasonal Dynamics of Surface Litter



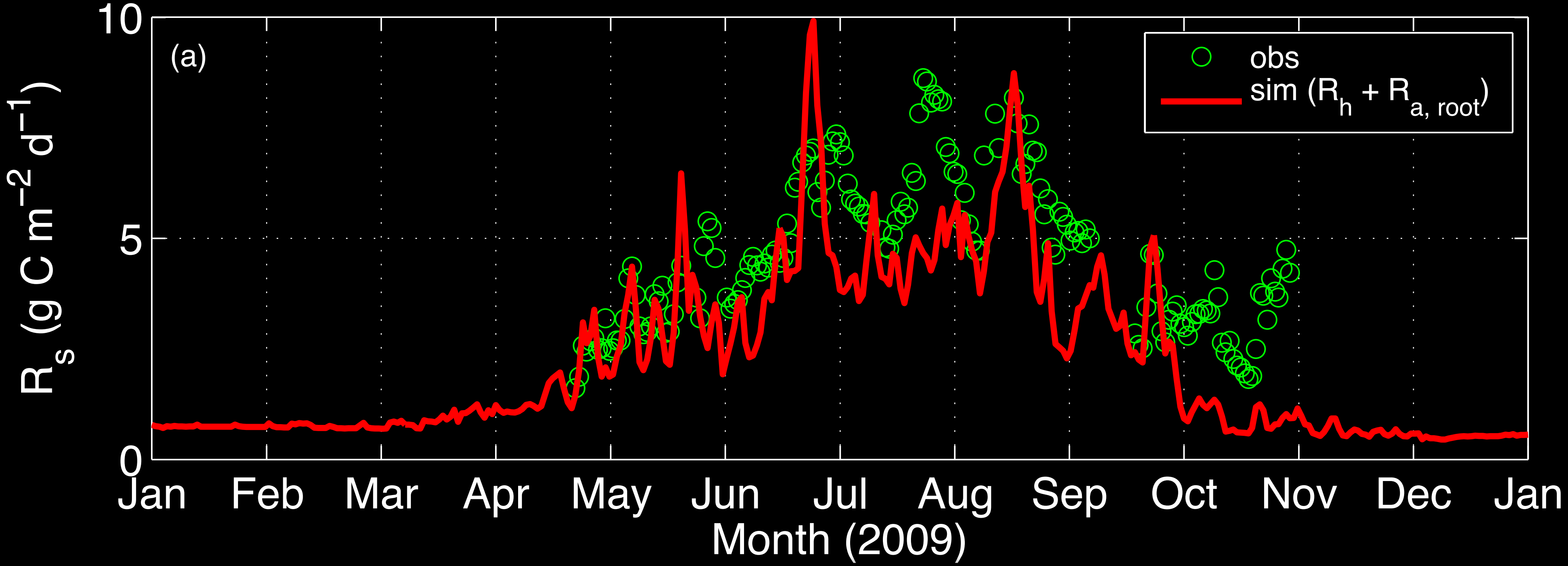
Seasonal Dynamics of Surface Litter



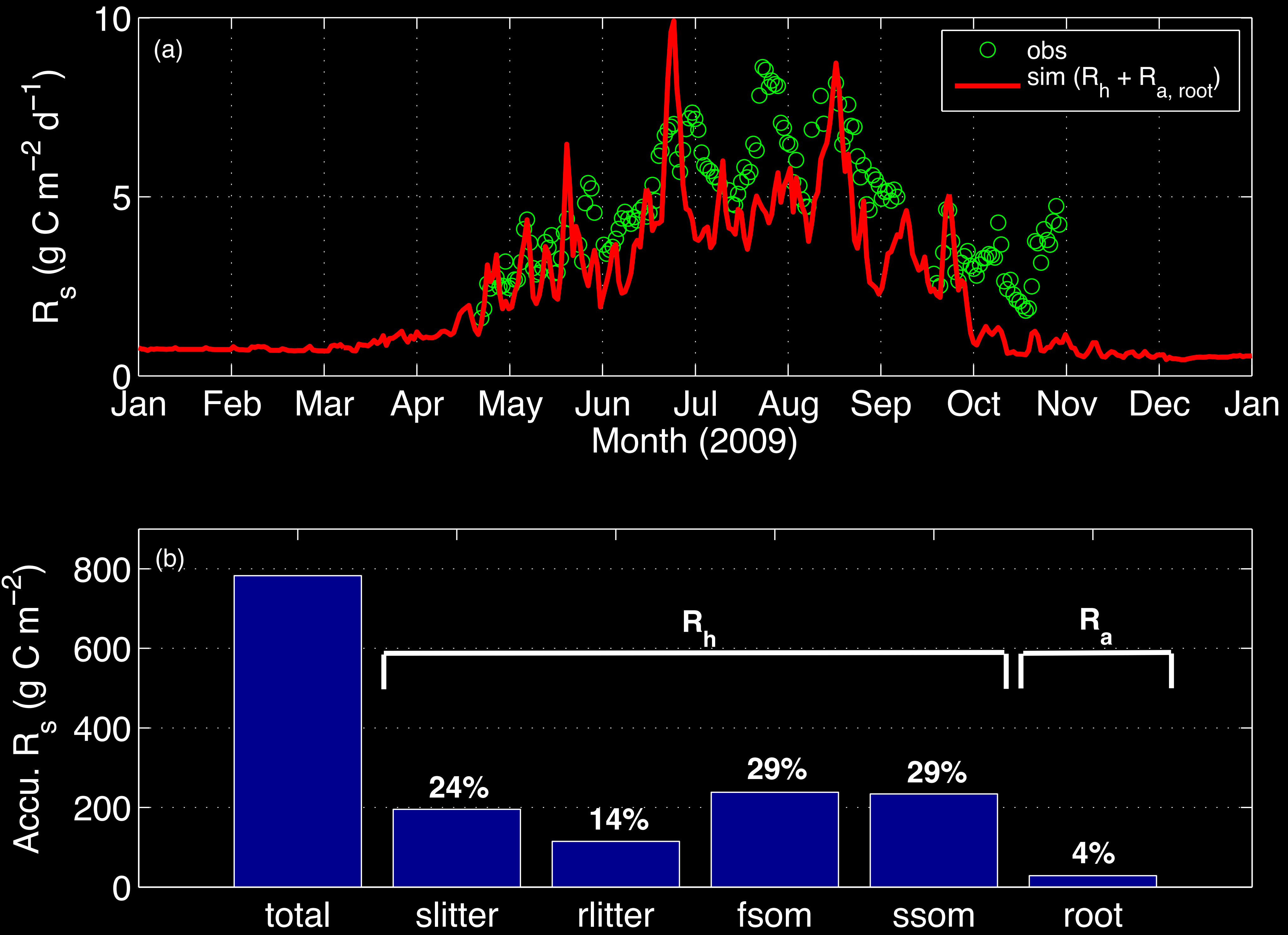
Surface Litter Partitioning



Soil Respiration Partitioning



Soil Respiration Partitioning



Conclusions

- First modeling study to quantify long-term carbon dynamics for my study sites at daily and half-hourly time-step
  - DayCENT is capable of simulating daily NEP under active agricultural management practices.
  - Conventional tillage enhances R_h by 60 to 90 g C m^{-2} yr^{-1}.
  - No-till increases carbon sequestration at a rate of 10.7 g C m^{-2} yr^{-1}.
- Improving Canadian Land Surface Model for agriculture
  - An agricultural schedule and a crop phenology scheme in CN-CLASS simulate a reasonable crop growth patten and carbon allocation.
  - Our modification improves the accuracy of NEP simulation by 53%.
- Quantifying and gap-filling the annual soil respiration for Borden deciduous forests
  - Soil CO_2 respiration is estimated at 782 g C m^{-2} yr^{-1}.

    ➡ Soil organic carbon : 60%; Litterfall/root respiration : 40%.

Implications

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1. Simulating biogenic GHGs distribution using the GEOS-Chem transport model.
2. Remote sensing data assimilation for LSM.

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Environment Canada Carbon Assimilation System
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4. Developing stable isotope-enabled STILT long-range transport model.

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Intercontinental Atmospheric Transport of Anthropogenic Pollutants to the Arctic (IATAPA)

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5. Developing a script-driven modeling procedure to stream polygon database and DayCENT.
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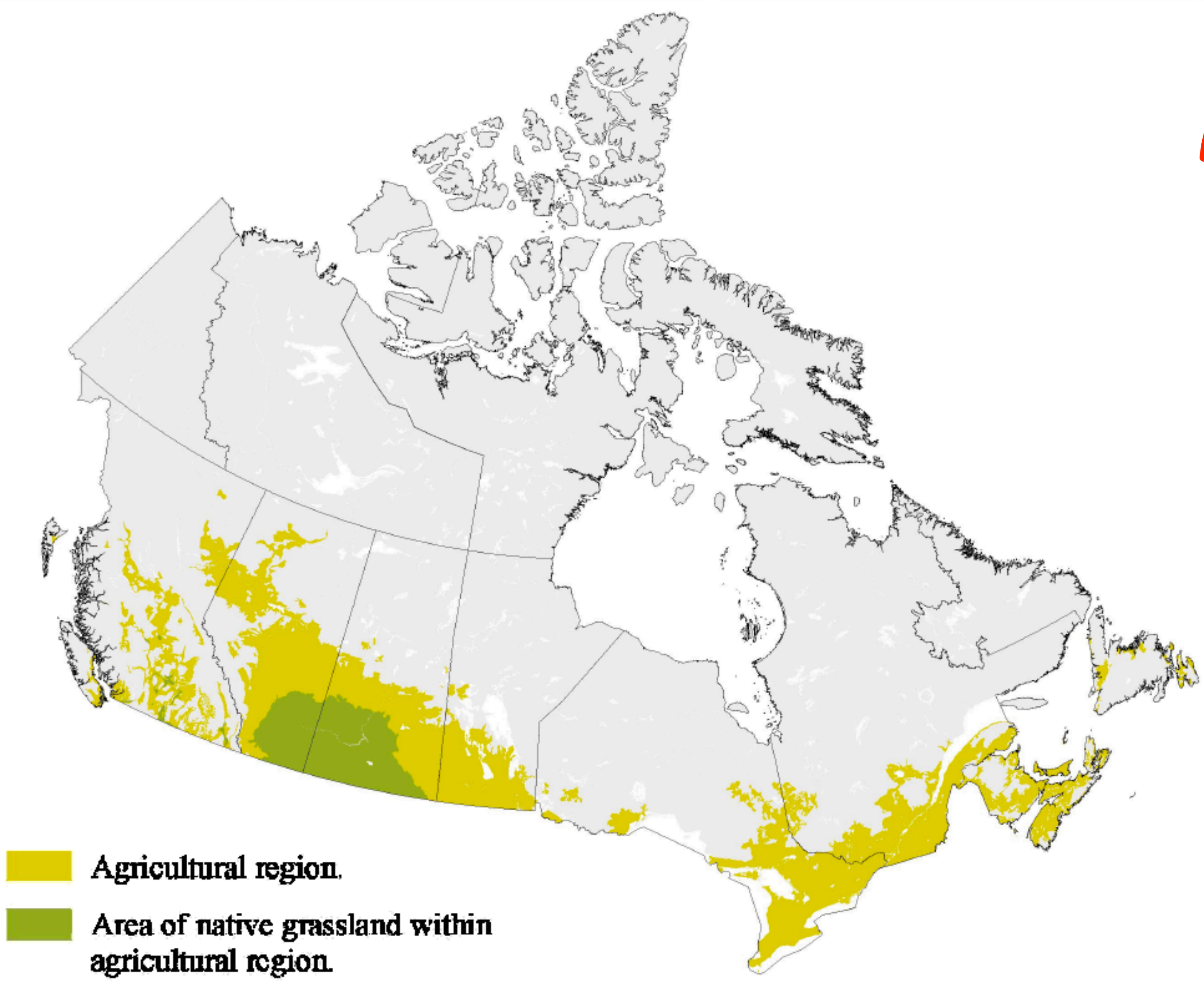
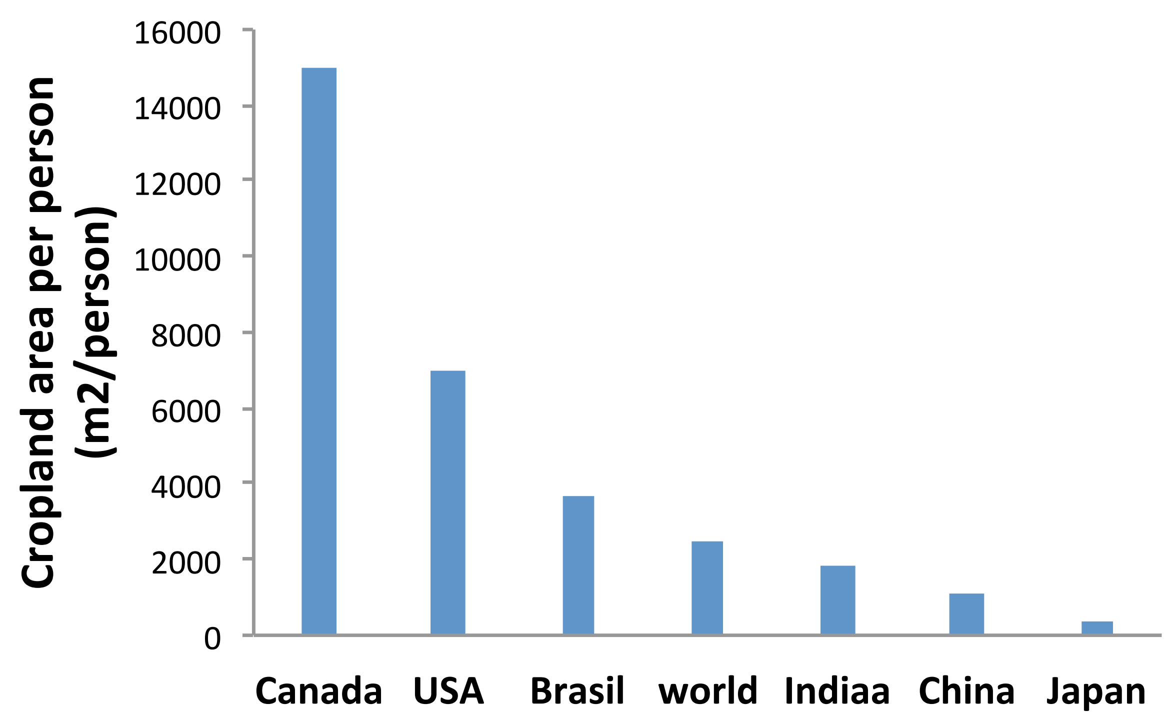
→ AAFC National Carbon and Greenhouse Gas Accounting and Verification System (AAFC−NCGAVS)



Agricultural land: 676000 km²
21x terrestrial area in Taiwan



What is NCGAVS ?

- National Carbon and Greenhouse Gas Accounting and Verification System
- National quantification of agricultural emissions of :
  1. Land carbon (C) stock change
     - From land use, land-use change, and forestry
  2. Nitrous oxide (N_2O) emissions
     - From nitrogen applied to land in fertilizer, manure, and legumes
  3. Methane (CH_4) emissions
     - From livestock and manure storage

Tier 2 Empirical approach

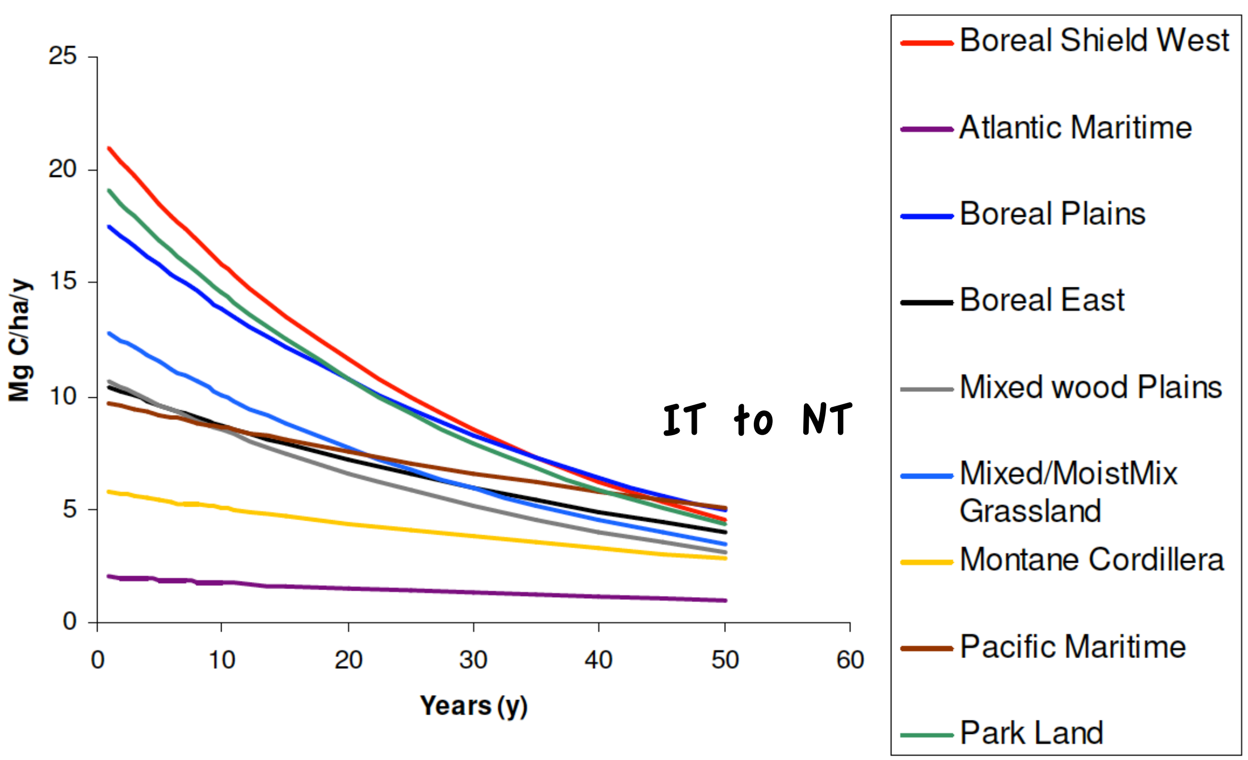
$$\Delta C = F \times A$$

ΔC : change in soil C stock

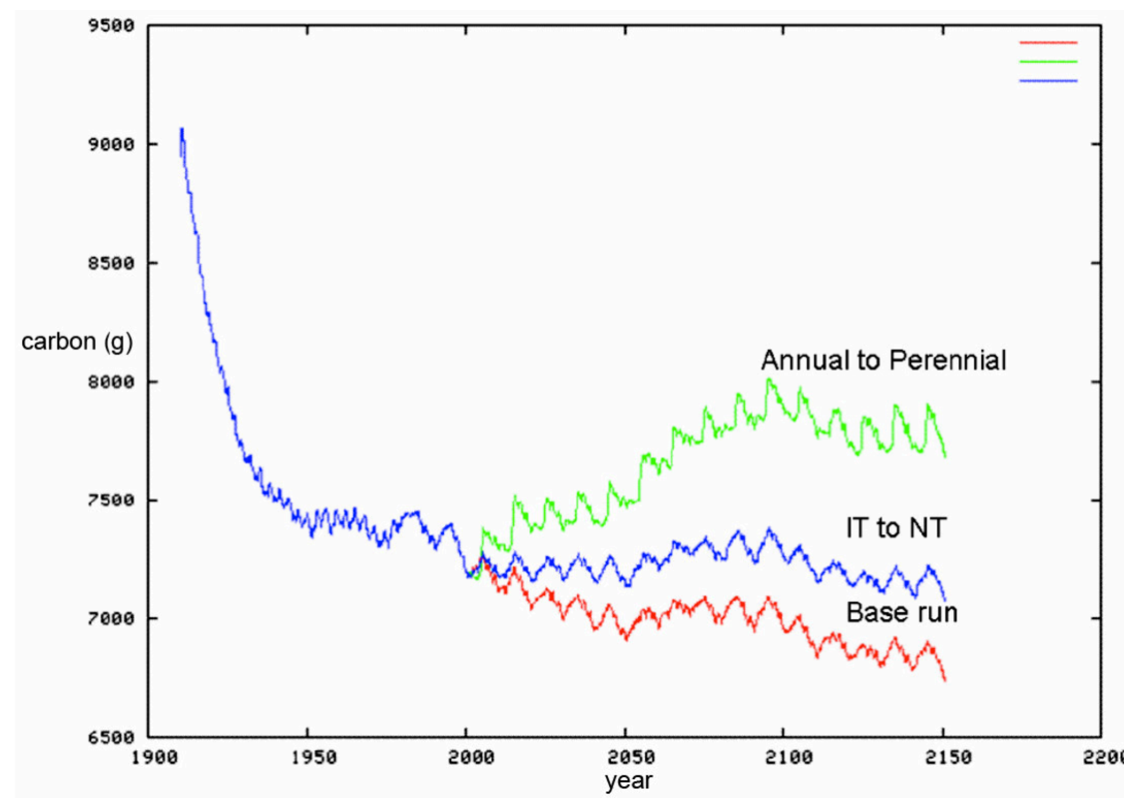
F : emission factor $= \Delta C_{max} \times e^{-k}$

A : area of land management practice

Emission factor



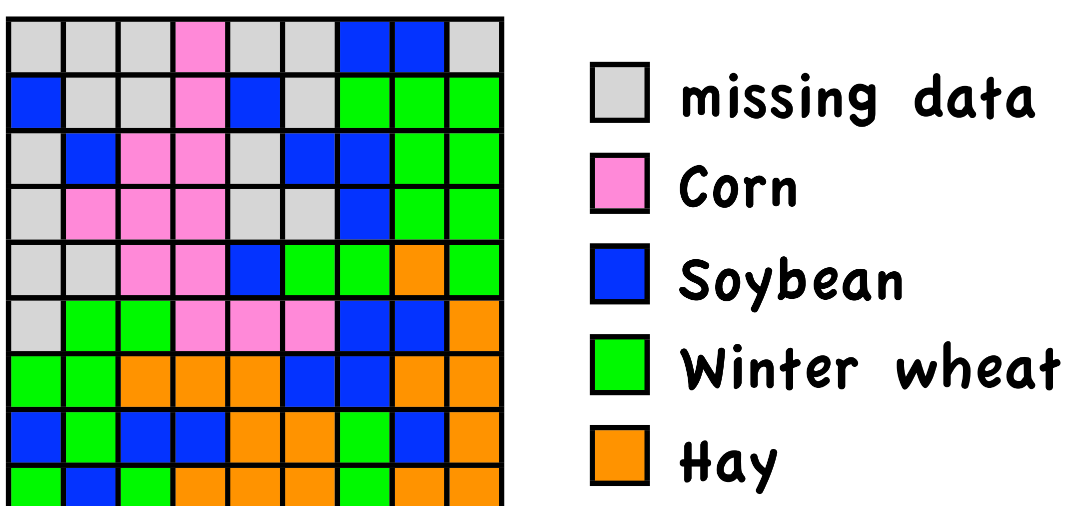
Soil C stock



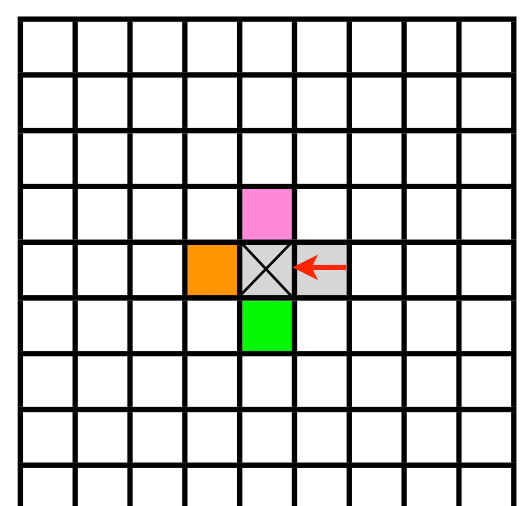
Tier 3 Process-based modeling approach

- Designing a modeling procedures to bridge the Soil Landscape of Canada (SLC) polygons and land surface models
- How to quantify C & GHGs using the "imperfect" polygons and census datasets

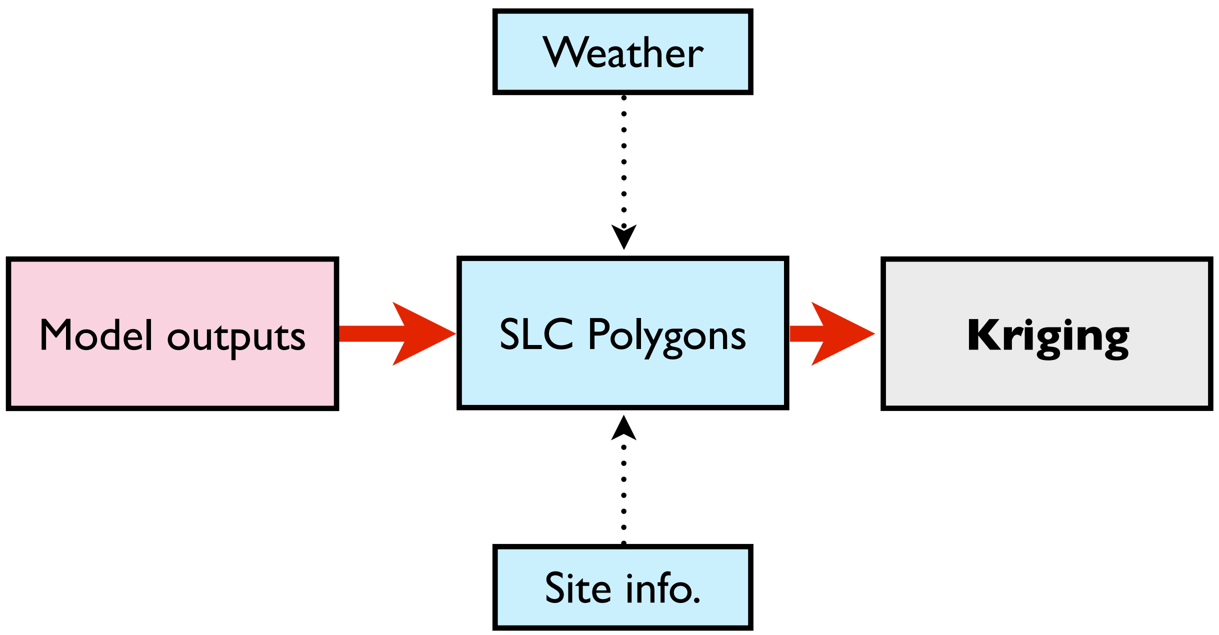
"imperfect" polygons

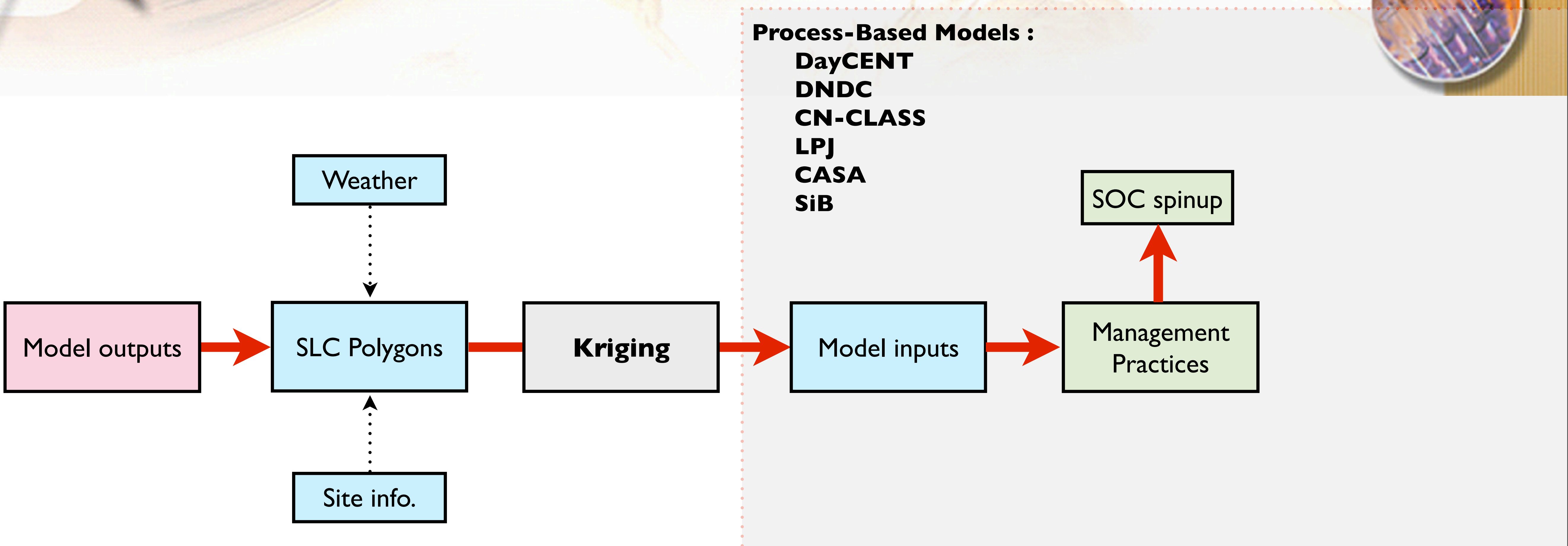


Gap-filled polygons



1. Kriging
2. Combination


Weather
Model outputs
SLC Polygons
Kriging
Site info.


Process-Based Models :
DayCENT
DNDC
CN-CLASS
LPJ
CASA
SiB
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SOC spinup
Model outputs
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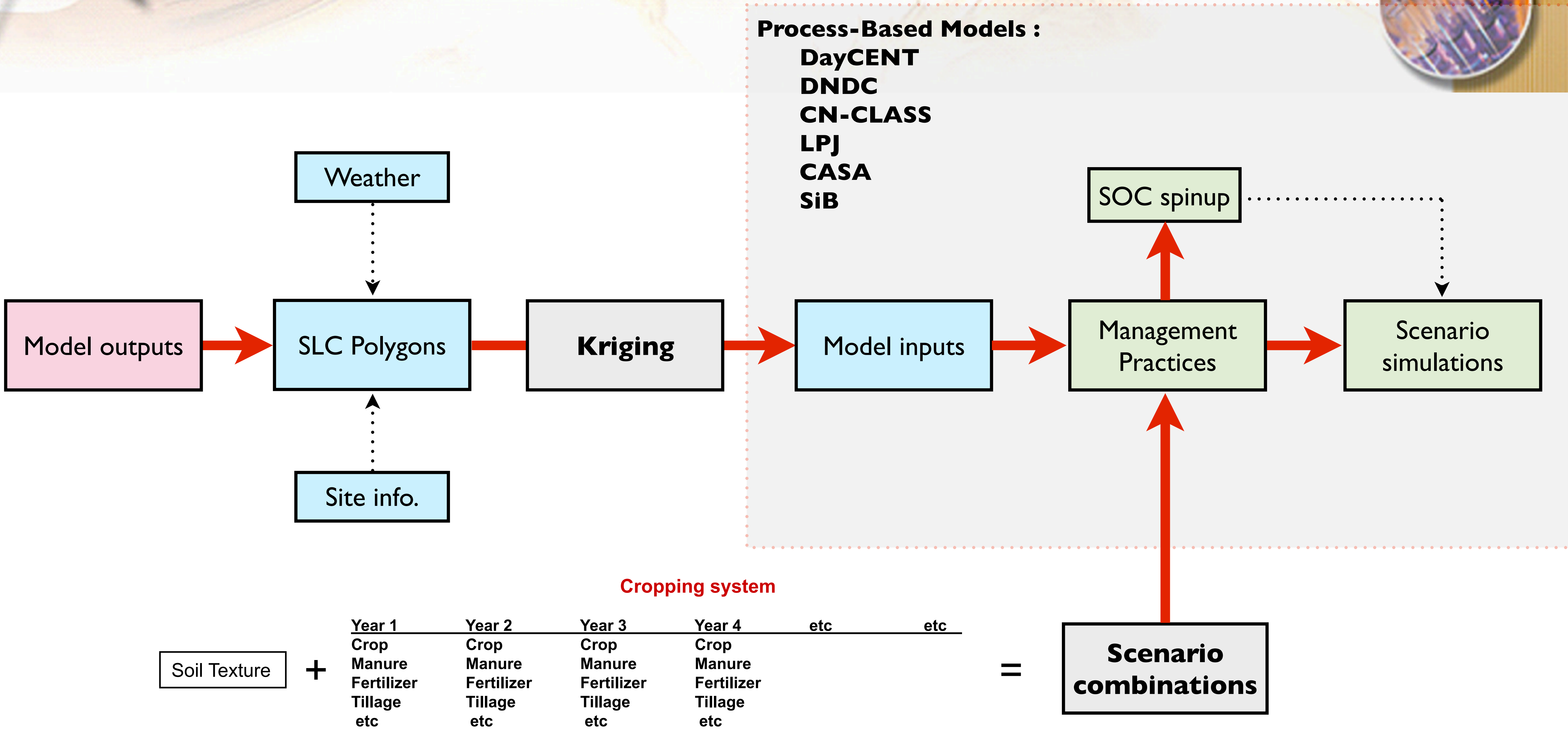
Management Practices
Site info.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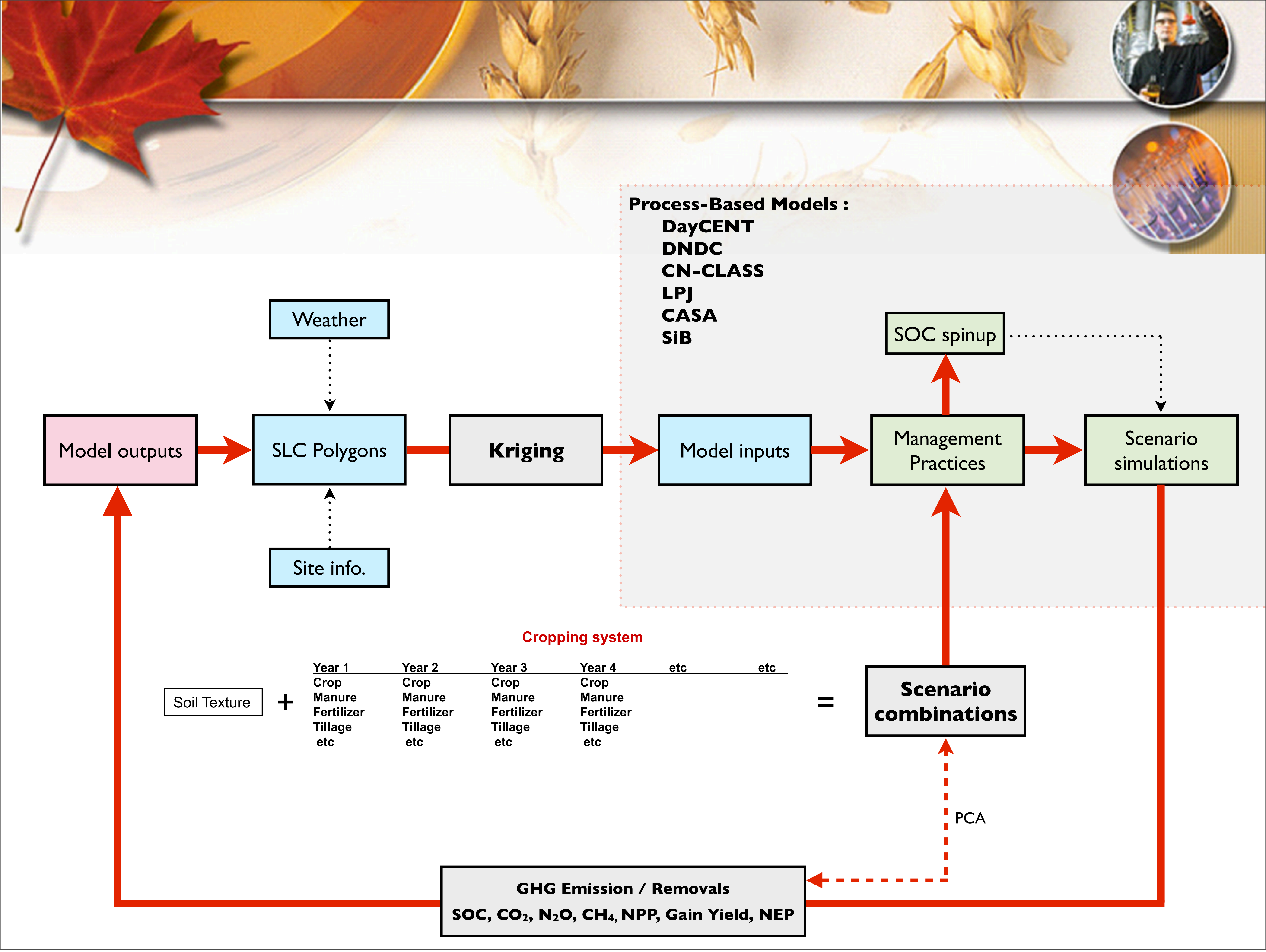
Scenario simulations
Site info.
Cropping system
Soil Texture
+
Year 1 Crop Manure Fertilizer Tillage etc
Year 2 Crop Manure Fertilizer Tillage etc
Year 3 Crop Manure Fertilizer Tillage etc
Year 4 Crop Manure Fertilizer Tillage etc
etc
etc
=
Scenario combinations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Year 1
Crop
Manure
Fertilizer
Tillage
etc
Year 2
Crop
Manure
Fertilizer
Tillage
etc
Year 3
Crop
Manure
Fertilizer
Tillage
etc
Year 4
Crop
Manure
Fertilizer
Tillage
etc
etc
etc
=
Scenario combinations
PCA
GHG Emission / Removals
SOC, CO_2, N_2O, CH_4, NPP, Gain Yield, NEP

Acknowledgment

Dr. Jon Warland: kindly financial support and supervise

Dr. Paul Bartlett: great help on paper proof-reading and model coding

Dr. Altaf Arain: generously sharing the code and provide insightful suggestion

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My Special Thank You Goes To :

Daily version of CENTURY (DayCENT): http://www.nrel.colostate.edu/projects/daycent

DeNitrification-DeComposition (DNDC): http://www.dndc.sr.unh.edu/

Canadian Land Surface Model (CN-CLASS): http://www.geog.mcgill.ca/CGC3M

Lund-Potsdam-Jena Model (LPJ): http://www.pik-potsdam.de/research/projects/lpjweb

Carnegie Ames Stanford Approach (CASA): http://geo.arc.nasa.gov/sge/casa

Simple Biosphere Model (SiB): http://www.atmos.colostate.edu/sib

Contact: kchang@uoguelph.ca